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THE PEGMATITES OF FITCHBURG, MASSACHUSETTS

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The pegmatites which form the subject of this paper are exposed in the McCauliff quarry at Rollstone Hill on the western outskirts of the town of Fitchburg, Massachusetts. They occur as vein-like masses within the Fitchburg granite which Emerson[1] regards as the typical rock of the core of the great central batholith of southern New England. The pegmatite bodies themselves are of an interesting and peculiar type and consist of a number of members which show some variation in size, emplacement, and mineral content. Graphic granite—so common in many of the New England pegmatites—is here entirely absent, and there is also little evidence of later hydrothermal activity. At the same time, a number of interesting auto-metamorphic effects are observed which might well be described as "deuteric," if that term may be used to imply late-stage magmatic effects within a closed system.

The granite of Rollstone Hill has been described by Emerson[2] and by Dale,[3] and consists of a fresh medium grained muscovite-biotite-microcline granite showing a gneissic structure due to a rude layering of the darker constituents. Isolated clots of mafic constituents largely consist of biotite, and represent xenoliths of schist in various stages of assimilation.

Microscopically, muscovite is seen in frequent association with biotite, the latter being particularly fresh and showing well-marked haloes around included zircons. Feldspars consist of early plagioclase of a composition varying between oligoclase and albiclase, a little orthoclase, and much microcline. Quartz is present in moderate quantity and encloses myriads of minute rutile needles. The accessory minerals consist of apatite and zircon together with small variable quantities of tourmaline and garnet. One of the most striking features is the abundance of myrmekitic intergrowths of quartz and albitic plagioclase which, together with small irregular masses of albite, encroach upon the borders of orthoclase and microcline, and also occur within them. Sederholm[4] has noted that myrmekite is commonest in those granites which have assimilated basic rocks, and in the present case there can be little doubt that the granite has assimilated large quantities of chloritic schist. In a recent discussion on the origin of myrmekite, Hills[5] lends support to the original hypothesis of Väyrynen,[6] namely that it results from the crystalloblastic development of biotite, in which change plagioclase and quartz are liberated.

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[1] Emerson, B. K. Geology of Massachusetts and Rhode Island: *U.S.G.S., Bull.* **597,** p. 231.

[2] Emerson, B. K. *op. cit.*, p. 232.

[3] Dale, T. N. The Chief Commercial Granites of Massachusetts, New Hampshire, and Rhode Island: *U.S.G.S., Bull.* **354,** p. 46 (supplement).

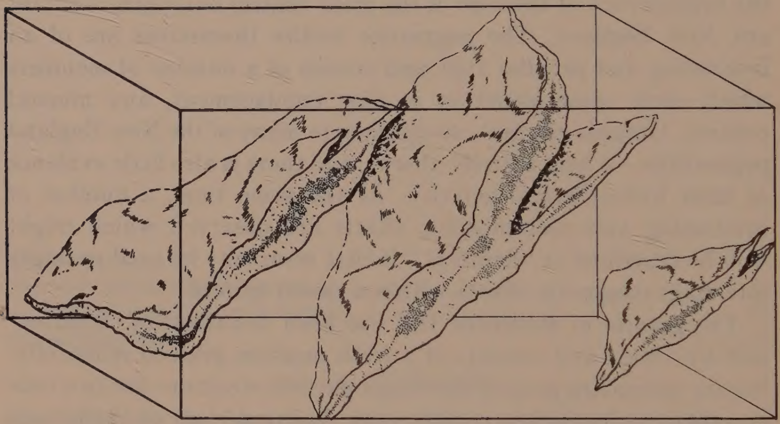

FIG. 1. Ideal sketch illustrating the occurrence of the principal tourmaline type pegmatites at Fitchburg.

The pegmatites occur within the granite, sometimes as well defined veins and veinlets, sometimes as small pipe-like bodies, and sometimes as masses of highly irregular shape. In all cases they show a frozen contact with the enclosing rock and never contain cavities. In general, field observations tend to show that the larger members form irregular lenses and dip northwards at angles varying from 40 to 60 degrees (Fig. 1). This is in harmony with Andersen's[7] observations, for he states that, while pegmatites have fairly parallel sides, they taper off within a short distance and are actually more lens than dike-shaped.

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[4] Sederholm, J. J. On Synantetic Minerals and Related Phenomena: *Bull. Comm. Géol. de Finlande*, no. **48,** 1916.

[5] Hills, E. S. An Unusual Occurrence of Myrmekite: *Geol. Mag.*, vol. **LXX,** p. 294, 1933.

[6] Väyrynen, H. Petrologische Untersuchungen der Granito-dioritischen Gesteine Süd-ostbothniens: *Bull. Comm. Géol. de Finlande*, no. **57,** 1923.

All the pegmatites tend to die out as they reach the granite forming the top of the hill, and there is reason to believe that the upper surface of the present hill is not far below the original contact surface of the granite with the schists which formerly covered it. Pegmatites similar to those of Rollstone Hill are found at other places on the Fitchburg granite outcrop, and Emerson and others mention such pegmatites as passing out into the surrounding schists. This is not unlikely, but no case of extra-granitic occurrence was noted in the vicinity of the McCauliff quarry.

As already mentioned, the pegmatites of Fitchburg show some variation in size, texture and mineral content, and it has been found possible to classify them into several distinct types, as follows:

I. Biotite Type.
II. Tourmaline Type.
III. Beryl Type.
IV. Titanite Type.
V. Allanite Type.
Calcite Veins.

With the exception of one beryl-bearing member, all the larger pegmatites belong to the Tourmaline Type; the remainder being represented by insignificant veinlets and stringers. Actually, the calcite veins can hardly be classified as pegmatites, but they appear to represent a concluding term in the sequence of post-magmatic events. The various types are noted in detail below.

I. Biotite Type

This is a somewhat subordinate type occurring in the form of thin meandering stringers, which rarely exceed two inches in thickness, and which present an irregular contact with the enclosing granite. The principal minerals consist of biotite, microcline, muscovite, and quartz: tourmaline is entirely absent and no primary plagioclase was encountered in any of the specimens studied.

Under the microscope, biotite is found to be particularly fresh and free from included zircon; it is associated with primary muscovite and a little magnetite. In hand specimens microcline presents a faint bluish translucent appearance, and microscopically is seen to contain a smaller amount of perthitic albite than in the other types of pegmatites; it is also comparatively free from incipient kaolinization. The only deuteric effect consists of the development of small masses and isolated crystals of albite both around and within the microcline crystals. This effect, so noticeable in the case of the other types of pegmatite, is relatively insignificant in the biotite veinlets. Another late-stage effect consists of the development of sericite in fissures traversing the primary minerals. Accessory minerals are negligible and only rarely are small zircons imbedded in the microcline.

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[7] Andersen, O. Discussions of certain phases of the genesis of pegmatites: *Norsk. Geol. Tidsskr.*, vol. **XII**, p. 6, 1931.

An examination of the biotite veinlets leads to the conclusion that they represent an early, highly potassic differentiate of the residual mother liquor (restmagma).

II. Tourmaline Type

This type includes the largest and most abundant pegmatites in the McCauliff quarry. They occur in the vein-like, though actually lenticular masses already described, and present a striking contrast with the enclosing granite. The lenses of the larger mem-

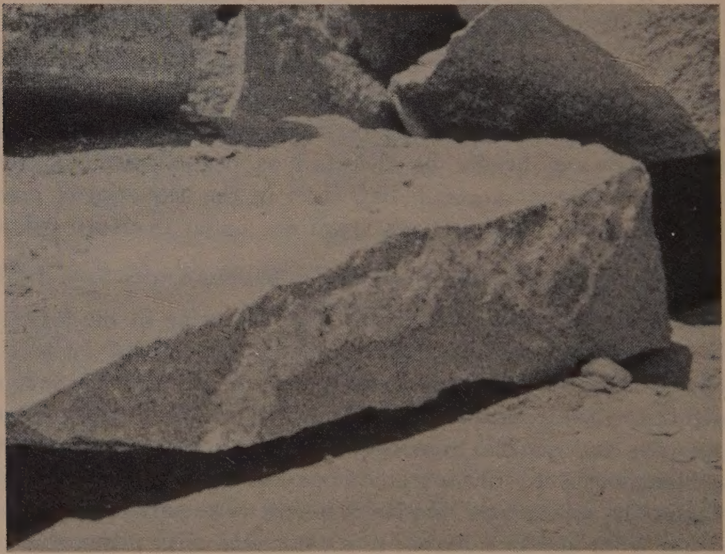

Fig. 2. Vein-like form assumed by a minor tourmaline type member, enclosed in granite.

bers sometimes possess a maximum thickness of 3 to 4 feet, although a thickness of 1 to 2 feet is more normal.

White feldspar occurs coarsely crystallized upon the selvages and also as "phenocrysts" set in the purplish-brown quartz which usually fills the center of each lens (Fig. 3). Typical crystals of black tourmaline (schorlite) are embedded both in the feldspar and quartz, and are remarkable for the manner in which they have been fractured and off-set, and "healed" by later quartz and feldspar (Fig 4). Another interesting feature is the replacement of individual tourmaline crystals by quartz along a central core parallel to the vertical axis, the phenomenon being most noticeable in the case of fractured crystals. The proportions in which feldspar, tourmaline, and quartz are present vary considerably—even in different portions of the same lens. Especially is this true of tourmaline, which sometimes constitutes 8–10 per cent of the pegmatite, and at other times is entirely absent—at least locally. Megascopically, the texture is very variable but in general corresponds to the width of the lens at any given place. Occasional bunches of muscovite mica form the only important accessory mineral.

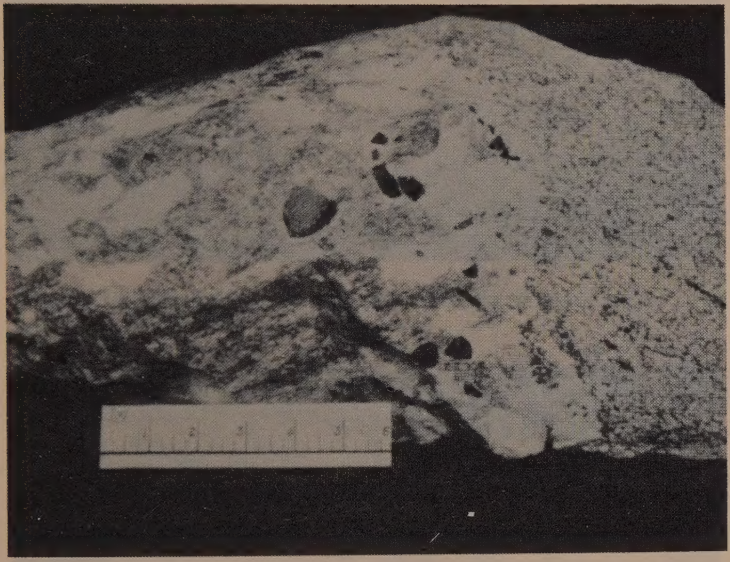

FIG. 3. Cross-section of a tourmaline type pegmatite showing white feldspar crystallized on the walls, and purplish-brown quartz occupying the center.

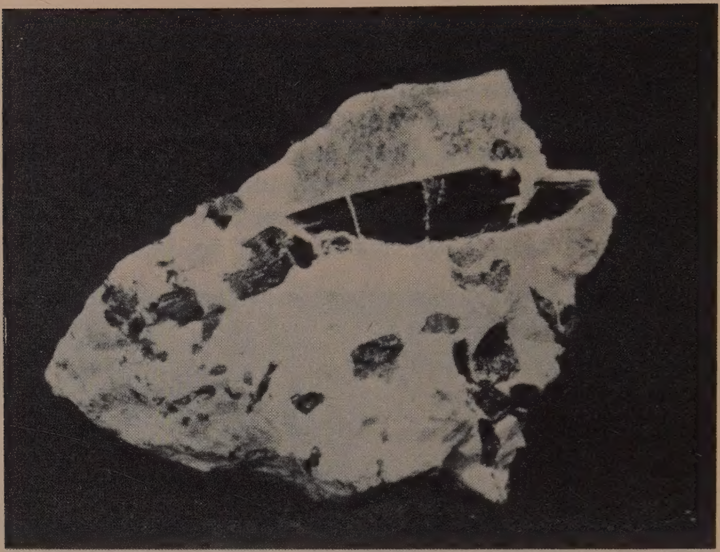

FIG. 4. Tourmaline crystal, fractured, off-set, and "healed" by later quartz and feldspar.

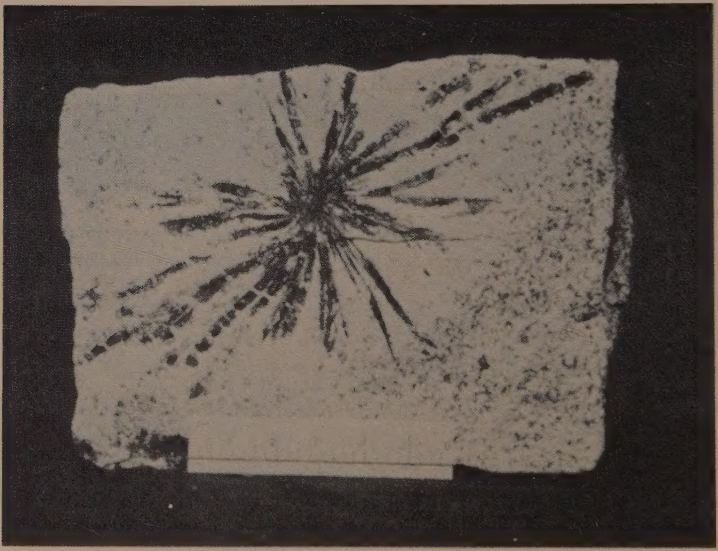

FIG. 5. Fine specimen of a "sunburst" of radiating tourmaline needles preserved in the Harvard Museum. The "sunburst" is associated with a white feldspathic matrix (just visible) similar to that forming the filling of the titanite veinlets.

Microscopically, the feldspar is found to consist of microcline and plagioclase, the former being greatly in excess. Various perthitic intergrowths are observed in the microcline which are fully described under "Mineralogical Notes." The plagioclase ranges in composition between albiclase and oligoclase and shows both albite twinning and a combination of albite and pericline twinning. Occasional anti-perthitic structures are sometimes observed in the plagioclase in the form of small irregular patches of microcline. During the early stages of formation, feldspar and tourmaline apparently crystallized together, but the former continued to crystallize long after the latter had completely separated. Quartz was the last mineral to crystallize and is found enclosing earlier minerals and filling fissures. Inclusions in the feldspar consist of occasional grains of apatite, zircon, tourmaline, muscovite, and chlorite.

Deuteric and related effects observed microscopically in the tourmaline type pegmatites consisted of:

(a) development of occasional patches of myrmekite,
(b) coarse vein perthite in microcline,
(c) veinlets of microcline traversing plagioclase,
(d) development of small albite crystals and quartz around the borders of, and within the microcline, the effect being of a similar character to that described by Colony.[8] In places where it has thus been attacked, the microcline tends to develop cloudiness,
(e) development of sericite along thin fissures traversing quartz and feldspar.

Biotite, despite its abundance in the Type I veinlets, is entirely absent from the tourmaline-bearing members, and these two minerals are never found to occur together in the same pegmatite. Similar observations have been recorded by Bastin[9] andMegathlin[10] in the case of the Maine and the New Hampshire pegmatites respectively. Some have suggested that tourmaline and biotite are mutually exclusive minerals, but a more satisfactory explanation appears to lie in the assumption that most pegmatite magmas yielding tourmaline were endowed with sufficient boron to convert all ferromagnesian constituents to that species. With insufficient

[8] Colony, R. J. The final consolidation phenomena in the crystallization of an igneous rock: *Jour. Geol.*, vol. **31**, p. 169, 1923.

[9] Bastin, E. S. Geology of the Pegmatites and Associated Rocks of Maine: *U.S.G.S., Bull.* **445**, p. 16, 1911.

[10] Megathlin, G. R. The pegmatite dikes of the Gilsum are , New Hampshire: *Econ. Geol.*, vol. **24**, p. 174, 1929.

quantities of boron only a partial conversion ensues and biotite and tourmaline then occur side by side—as, indeed, actually happens in the case of some of the assimilated xenoliths of schist. The idea that tourmaline may be formed at the expense of biotite appears to have been first suggested by Patton in 1898.[11]

The fact that a large number of the tourmaline crystals are broken and off-set, while only relatively few of the feldspar crystals are thus affected, indicates that this protoclastic shattering took place at a stage when most of the tourmaline had separated, and a large amount of quartz and feldspar still remained uncrystallized. Megathlin[12] reports similar shattering of the tourmaline in the case of the Gilsum pegmatites and attributes it to "readjustment during crystallization"; he does not, however, state whether he believes such readjustment to be the result of internal or external forces. In the case of Fitchburg, the writer is inclined to the view that shattering was produced by external forces acting on the granite, which caused deformation of the enclosed pegmatites.

III. BERYL TYPE

As far as is known, this type is represented by only one member which occurs at the southern end of the quarry, others, however, may exist beneath the granite debris which covers the quarry floor and the adjacent hill slopes. While resembling the tourmaline type members described above, this beryl-bearing pegmatite is more definitely dike-like in character, and has a width of 1 to 1½ feet with fairly parallel walls.

As usual, white feldspar is clustered along the vein selvages and also occurs as "phenocrysts" towards the center of the vein. The filling consists of purplish-brown quartz and relatively large flakes of muscovite which are conspicuously grown on and around the feldspar phenocrysts. A small quantity of black tourmaline is present, most of it being embedded in the feldspar a short distance inwards from the granite contacts on either side. Almandine garnet and beryl are peculiar to this type of pegmatite and commonly occur associated with the quartz and muscovite. Individual beryl crystals are broken and off-set in a similar manner to the tourmaline of the Type II members. The structure of this pegmatite is illustrated in Fig. 6.

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[11] Patton, H. B. *Bull. Geol. Soc. Amer.*, vol. 10, p. 21, 1898.

[12] Megathlin, G. R. *op. cit.*, p. 174.

Examined microscopically sections of the beryl-bearing pegmatite are found to exhibit similar features to those encountered in sections of members belonging to the tourmaline type. Feldspar mainly consists of coarsely crystallized microcline-microperthite with a little plagioclase showing anti-perthitic structures. Late-stage magmatic effects, etc., are identical with those described under Type II, except for the fact that minute pink crystals of almandite accompany sericite in fissures traversing quartz and feldspar.

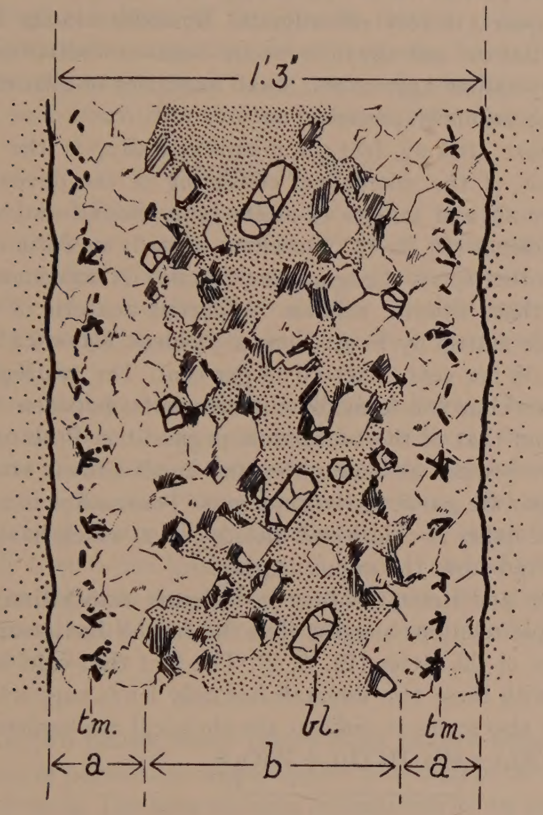

Fig. 6. Cross-section of the beryl vein: (a) outer zones consisting of feldspar and small amounts of tourmaline (tm.), (b) center zone of feldspar, muscovite, and beryl (bl) embedded in quartz.

iv. Titanite Type

Members of this somewhat rare type occur as meandering veinlets only a few inches in width, and might well escape casual observation owing to their similarity to the enclosing granite, and their gradational contact with it. Their filling consists of white feldspathic material of a texture only a little coarser than that of the granite. Muscovite mica is fairly abundant in individual crystals, but quartz is very subordinate. Embedded in the feldspathic matrix, titanite and ilmenite occur both as individual crystals and as crystalline aggregates. Small quantites of allanite and calcite are occasionally present.

The most striking feature microscopically, is the advanced albitization of the microcline, consisting of the development of small crystals and masses of albite both around and within the potash feldspar (Pl. A, 1). This effect, already noted in connection with the other types of pegmatites, reaches its maximum development in these titanite veinlets. A partial analysis of the white feldspathic matric by F. A. Gonyer yielded: $K_2O = 9.87$ per cent, $Na_2O = 3.38$ per cent, $CaO = 0.52$ per cent. The grating structure of the microcline is intermediate in coarseness between that of the granite and that of the tourmaline pegmatites. Both apatite and garnet are present as accessories and small zircons embedded in the feldspar are particularly numerous. Tourmaline is absent, but occasional flakes of chloritized biotite occur, which have probably been derived from the adjacent granite.

Titanite and ilmenite occur in intimate association and their microscopic relations suggest that the former has resulted by replacement of the latter (Pl. A, 2). The fact that calcite occurs in contact with these two minerals not only lends support to such a view, but also seems to indicate the chemical mechanism involved.

$$\underset{\text{ilmenite}}{3(FeO,\ TiO_2)} + \underbrace{3Ca(HCO_3)_2 + 3SiO_2}_{\text{in solution}} = \underset{\text{titanite}}{3(CaO,TiO_2,SiO_2)} + \underset{\text{removed in solution}}{3Fe(HCO_3)_2}$$

There is reason to believe that calcium bicarbonate may be stable in hydrothermal solutions, provided the amount of carbon dioxide and the pressure are sufficiently great.

Observations on these stringers suggest that they were derived from a more sodic differentiate, which was capable of a greater degree of auto-metamorphism, than the more potassic fractions represented by pegmatites of types I, II, and III. The titanite and ilmenite, and the greater abundance of small zircon crystals are, of course, consistent with a more sodic environment. The gradational contact of these stringers with the granite would seem to point to the more aqueous, and penetrating character of this sodic differentiate—especially during auto-metamorphism when albite and quartz replaced the potash feldspar. The residual liquors active at that stage succeeded in passing beyond the confines of the pegmatite, and have produced albitization of the microcline, and chloritization of the biotite in the adjacent granite.

v. Allanite Type

The allanite at Fitchburg is mostly confined to extremely thin, though well-defined quartz stringers, which pass through the granite independently and rarely attain a greater width than half an inch. At certain points these allanite veinlets intercept the tourmaline (type II) pegmatites, and they are consequently younger than the latter.

Blocks containing these allanite veinlets have a tendency to split along the plane of the vein, and thus to reveal the greenish-black allanite in the form of flattened, prismatic crystals which are grouped, sometimes into stringy fibrous patches, and sometimes into stellate aggregates. With the exception of uraninite, which has recently been noted by Prof. A. C. Lane,[13] and which appears to have been found in association with allanite the stringers contain no other minerals in addition to quartz, allanite, and metamict products of the latter.

Calcite Veins

In one or two places, small calcite-filled fissures occur, which, although not of pegmatitic origin, appear to complete the sequence of igneous events. The vein selvages are marked by an abundance of minute albite crystals, small quantities of purple fluorite, and larger and more perfect plates of ilmenite and muscovite which protrude into the brownish calcite filling the center of each vein. The structure and mineral assemblage are seen to advantage when the calcite has been removed by acid.

Mineralogical Notes

In his appendix to his "Catalogue of American Minerals," published in 1825, Robinson mentions quartz, mica, schorl, beryl, and sulphuret of molbydena, as occurring at Pearl Hill, five miles north-east of the "village" of Fitchburg. This, persumably, is the first reference to Fitchburg minerals. A similar suite was discovered when the McCauliff quarry was opened in 1865.

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[13] Lane, A. C. Age of Fitchburg Granite: *Science*, vol. **78**, p. 435, 1933.

TOURMALINE. As schorlite this mineral occurs abundantly in the type II pegmatites. Crystals are simple and of the usual prismatic habit with striated prism faces. In size they normally range from 0.5 cm. to 10 cms. in length, and from 0.1 cm. to 2.5 cms. in cross section; exceptionally large individuals measuring over 30×5 cms. have, however, been reported. The forms commonly present are $m(10\bar{1}0)$, $a(11\bar{2}0)$, and $r(10\bar{1}1)$; more rarely $o(02\bar{2}1)$ is observed. In complete specimens hemimorphism is expressed by termination at one end by $r(10\bar{1}1)$, and at the other by $r(10\bar{1}\bar{1})$ and $o(02\bar{2}\bar{1})$. Ward[14] gives the refractive indices as $\epsilon=1.638$ and $\omega=1.664$.

The crystals are remarkable for two structures:

(a) they have frequently been transversely fractured, the cracks having been "healed" by later quartz and feldspar (Fig. 4).
(b) they often show quartz cores which appear to be the result of a replacement that most readily took place along a direction parallel with the vertical axis.

Under the microscope, thin sections of the large tourmalines show normal characters and are, with the exception of occasional small zircons, free from inclusions. A study of the quartz cores (Pl. A, 3, 4) suggests that the mechanism of replacement consisted, first of a partial re-solution of the early formed crystals, the cavities so formed being then filled by quartz. Thousands of minute needles of tourmaline are seen in the quartz of the cores. The replacement is of a magmatic type and may have been effected by late-stage liquors. There is no evidence to suggest that it may have been due to the action of hydrothermal solutions.

In addition to the crystals described above, tourmaline occurs in several other ways, namely:

(a) as black "sooty" masses representing aggregates of innumerable microscopic crystals of schorlite;
(b) in a form constituting a crude graphic intergrowth with quartz, similar to the quartz-tourmaline intergrowths found in the Gilsum (N. H.) and certain of the Maine pegmatites;
(c) very rarely as clusters of radiating needles ("sunbursts") as illustrated in Fig. 5.

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[14] Ward, G. W. *Amer. Min.*, vol. **16**, p. 162, 1931.

The sooty variety (a) appears to be secondary, and may possibly represent a deposition of the material that was taken into solution during the replacement of the early formed crystals. The clusters of radiating needles (c) are associated with a relatively fine feldspathic matrix identical with that of the titanite veinlets. The individuals forming a cluster show transverse fracturing similar to that described above, but in the present case, the tourmaline has undergone considerable replacement by the white albitic matrix in which it is embedded. In places the tips of the crystals appear to penetrate the granite on either side of the vein. The origin of these peculiar "sunbursts" presents a difficult problem, but it is possible that they represent an early separation of tourmaline from the restmagma which gave rise to the titanite veinlets.

MICROCLINE (MICROPERTHITE). This mineral commonly occurs coarsely crystallized upon the walls of the Type II pegmatites, but a number of more perfect crystals are found embedded in the quartz occupying the center. These latter are best suited for purposes of study and normally measure 5 to 8 cms. along the *c*-axis. The forms present include,—

$c(001)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $f(130)$, $z(1\bar{3}0)$, $x(\bar{1}01)$, $y(\bar{2}01)$, $p(\bar{1}11)$, $o(\bar{1}\bar{1}1)$.

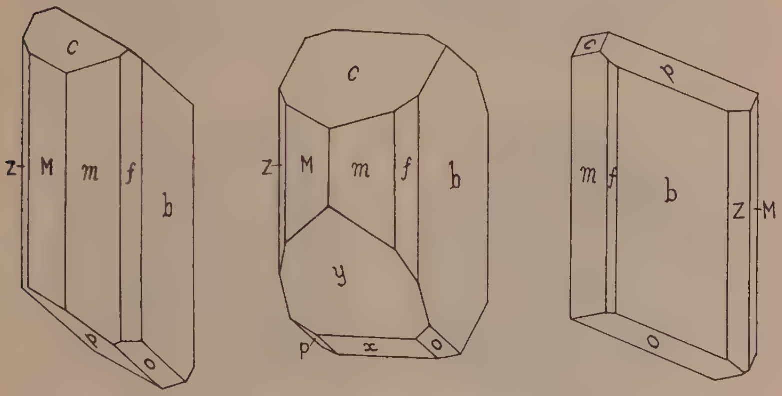

FIG. 7. Crystals of microcline.

Crystals are tabular with $p(\bar{1}11)$ sometimes prominent; in other cases only simple prisms and pinacoids are present (Fig. 7). Most crystals are twinned on the Carlsbad law and show a well marked murchisonite parting. Refractive index determinations gave: $\alpha=1.518$, $\beta=1.522$, $\gamma=1.527$. An analysis by F. A. Gonyer yielded:

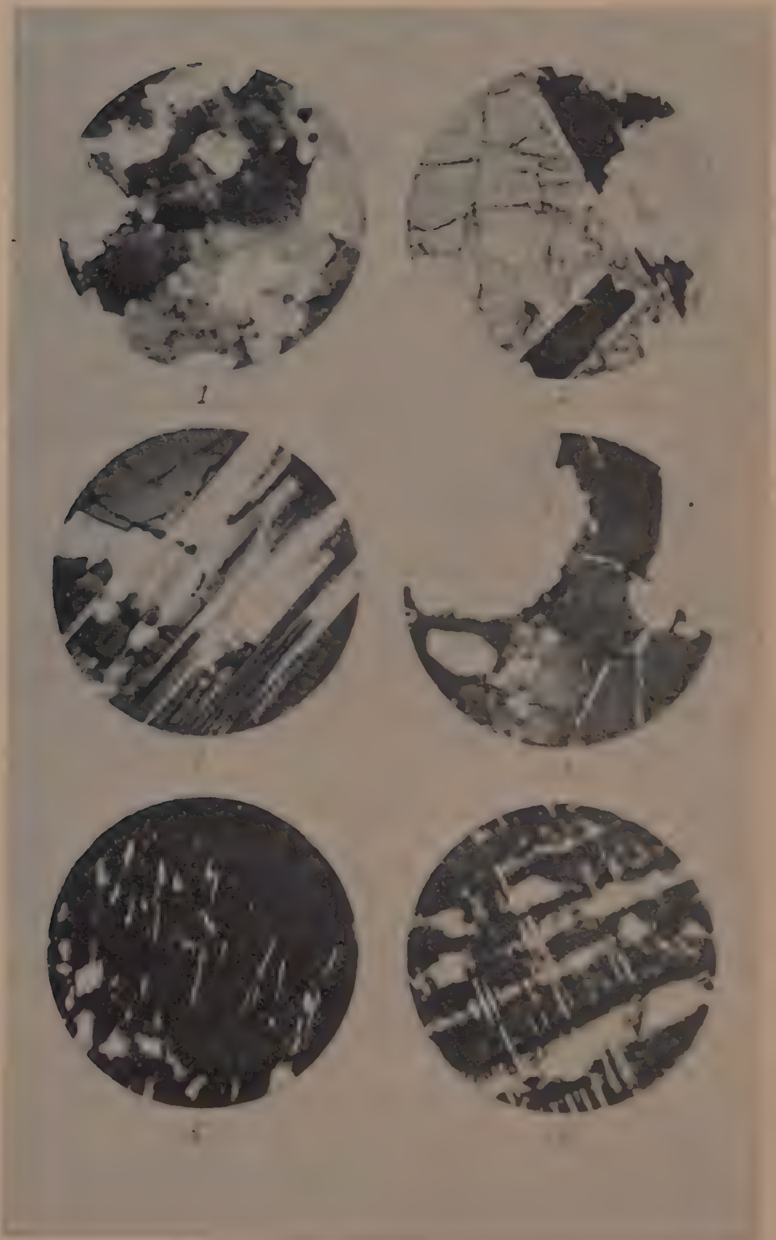

PLATE A

(1) Deuteric replacement of microcline by small masses of albite and myrmekitic intergrowths, in the feldspathic matrix of the titanite (type IV) veinlets. Crossed nicols.

(2) Titanite and ilmenite with intervening calcite. The titanite veinlets, ordinary light.

(3) Longitudinal section of tourmaline crystal, showing replacement by quartz along a direction parallel with the vertical crystallographic axis. Ordinary light.

(4) Similar to Fig. 3, but a transverse section. Ordinary light.

(5) Section of microcline cut parallel to (010), showing film perthite (fine striations). Crossed nicols.

(6) Section of microcline cut parallel to (001), showing cross-twinning and coarse vein perthite. Albite twinning of the latter just visible. Crossed nicols.

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	H_2O+	Total
Per cent	64.26	18.55	0.62	0.13	0.29	1.91	13.78	0.32	99.86

—from which the following mineral composition is computed:—

Orthoclase = 82.16%, Albite = 16.44%, Anorthite = 1.40%. According to Warren[15] microcline is only able to hold about 8% of albite in solid solution, any excess being represented by perthitic intergrowths as in the present case.

Microscopic Features—Sections parallel to (010). The fine microperthite associated with the murchisonite parting is clearly seen under crossed nicols, individual fibres or lamellae measuring from 1 to 2.5 mm. in length (Pl. A, 5). This microperthite although much coarser, is of a similar character to that described by Spencer,[16] and corresponds to the "film perthite" of Andersen,[17] which the latter regards as due to ex-solution, but probably at a lower temperature than his "string perthite." In this orientation (010) the angle between the fine lamellae of perthite and the basal cleavage is 73°

Coarse microperthite occurs fairly abundantly as stringy veins and lenticular patches occupying no special orientation: cut in this position, no twin lamellae are visible. This coarse perthite corresponds to the "vein perthite" of Andersen,[18] which he regards as due to solutions from the pegmatitic magma filling contraction cracks. Alling[19] suggests that in origin, such a form of perthite marks the boundary line between the deuteric and hydrothermal phases. Alteration products form cloudy patches on the peripheries of the blebs of coarse "vein perthite."

Sections parallel to (001). In this orientation both the characteristic cross twinning of the microcline and the lamellar twinning of the albite, forming the coarse "vein perthite," are observed under crossed nicols (Pl. A, Fig. 6). The finer "film perthite," however, is only barely visible and forms faint "striations" at right angles to the (010) cleavage. The whisps and lenses of "vein perthite" show a rude orientation parallel to the (100) edge.

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[15] Warren, C. H. A quantitative study of certain perthitic feldspars: *Proc. Amer. Acad. Arts & Sci.*, vol. **51**, p. 127, 1915.

[16] Spencer, E. A contribution to the study of moonstone from Ceylon and other areas and the stability-relations of the alkali feldspars: *Min. Mag.*, vol. **XXII**, pp. 291–365, 1930.

[17] Andersen, O. The genesis of some types of feldspar from granite pegmatites: *Norsk. Geol. tidsskrift*, B. X, h. 1–2, p. 149, 1928.

[18] Andersen, O. *op. cit.*, p. 150.

[19] Alling, H. L. Perthites: *Amer. Min.*, vol. **17**, p. 61, 1932.

OLIGOCLASE (ANTI-PERTHITE). Primary oligoclase occurs along with microcline as phenocrysts in the Type II pegmatites. Crystals are usually poorly developed, but contact measurements revealed the presence of the following forms:—

$c(001)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $y(\bar{2}01)$, $r(403)$, $f(130)$, $e(021)$.

In habit the crystals tend to be somewhat tabular parallal to $c(001)$ and resemble those from Fine, St. Lawrence Co., N. Y., described by Penfield.[20] Determinations of refractive indices yielded, $\alpha = 1.538$, $\beta = 1.542$, $\gamma = 1.545$. An analysis of the alkalies by F. A. Gonyer gave, $Na_2O = 7.72$ per cent, $K_2O = 2.06$ per cent—from which is calculated the following mineral composition: Orthoclase $= 12.58$, Albite $= 65.24$, Anorthite $= 22.58$ per cent (by diff.). The plagioclase is therefore oligoclase (Ab. 74.29, An. 25.71), the 12.58 per cent of potash feldspar being present, partly in solid solution, and partly as anti-perthitic blebs. Most authorities concede that, at ordinary temperatures, the solubility of the orthoclase molecule in albite is small, amounting to about 4–6 per cent. A higher figure of 8 per cent is given by Spencer.[21] In the present instance, the amount of potash feldspar occurring as anti-perthite is estimated at about 2–3 per cent, leaving some 9–10 per cent in solid solution in oligoclase.

Microscopic characters. Sections parallel to (001) show fine lamellar twinning possessing an extinction angle of 2°–3°. Irregular patches of anti-perthitic microcline are present, and thin "rafts" of secondary calcite traverse the section, inclined at an angle of about 85° to the direction of the lamellae. Sections parallel to (100) show the principal cleavage parallel to (001), which is rendered conspicuous by calcite filling—as are other fissures. The angle between the principal cleavage and the twin lamellae measures 93°.

BERYL. Beryls of gem quality are said to have been obtained at Fitchburg, but most of the material is of the ordinary translucent variety, ranging in colour from deep golden yellow to pale green. Individual crystals measure 0.3 to 2.0 cms. in diameter and consist of simple combinations of $c(0001)$, and $m(10\bar{1}0)$. They are frequently broken and off-set in a similar manner to the tourmalines.

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[20] See Dana, E. S., A System of Mineralogy, 6th Ed., p. 332.

[21] Spencer, E. *op. cit.*

The indices of refraction are, $\epsilon=1.578$, $\omega=1.585$, which, according to Winchell,[22] indicates an alkali content of about 2 per cent. There is a tendency for the smaller beryl crystals—especially those of a golden colour—to be clearer and more perfectly formed, and they may represent a somewhat later deposition.

Allanite. At Fitchburg, allanite is largely confined to thin quartz stringers which pass independently through the granite. The mineral usually occurs in them as fibrous-looking bunches of flattened, prismatic crystals, which possess a resinous lustre and range in colour from dark green to black. In places a superficial reddish-brown decomposition product has been formed by weathering. Individual crystals are invariably curved, and are usually too poor for accurate measurement, the following simple forms have, however, been identified:—

$$c(001),\ a(100),\ e(101),\ r(\bar{1}01),\ o(011).$$

The habit is similar to that of epidote, with $e(101)$ prominent. Grains show an extremely weak birefringence and possess an average refractive index of 1.69.

In thin sections, allanite itself—as distinct from its peripheral (metamict) alteration products—appears to consist of two substances, which are easily distinguished when a longitudinal section is viewed in polarized light. Both varieties are of a dull greyish green colour, but one is slightly darker and possesses well marked pleochroism (blue-green to red-brown). This pleochroic variety is anisotropic and polarizes in greys of a high order. The lighter variety is isotropic and non-pleochroic, and comprises the bulk of the material: in it are set lenses and "rafts" of the pleochroic variety. An orange coloured alteration product fringes the allanite and there are also small masses of associated opaque material.

These observations are in agreement with those of Watson[23] who has studied allanite from a number of localities in the eastern United States. He distinguishes a pleochroic and a non-pleochroic variety, and finds that the pleochroism and refractive indices of the former vary with different localities. He further finds that the orange alteration product possesses indefinite optical properties, and is of no fixed composition. It essentially consists of H_2O, Fe_2O_3, Al_2O_3, Ce_2O_3, and SiO_2, in varying proportions.

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[22] Winchell, A. N. Elements of Optical Mineralogy, *New York*, **1928**, Part II, p. 272.

[23] Watson, T. L. The weathering of allanite: *Bull. Geol. Soc. America*, vol. **28**, pp. 463–500, 1917.

GARNET (SPESSARTITIC ALMANDITE). Garnets at Fitchburg are confined to veins in the south end of the quarry, and are fairly plentiful in the beryl vein. Individuals sometimes measure over 2 cms. in diameter, and show the trapezohedron *n* (211) and the dodecahedron *d* (110) in combination, the former being usually dominant. The smaller crystals are transparent and of a fine ruby red colour; more rarely yellowish-red and pink tints are seen.

An analysis (by F. A. Gonyer) of carefully picked material yielded:—

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MnO	MgO	TiO_2	Total
Per cent	36.07	21.10	7.05	17.38	1.18	17.88	0.28	none=	100.94

from which the following mineral composition is calculated—

Almandite	52.49	per	cent.
Spessartite	41.53	"	"
Pyrope	0.92	"	"
Andradite	3.55	"	"
	98.49		

By orthodox calculation, amounts of silica, alumina, and ferric oxide remain over, which cannot be allocated to garnet species. The above composition is obtained by converting the balance of Fe_2O_3 to FeO and calculating as almandite. The remaining balances of SiO_2 and Al_2O_3 are thereby satisfied.

In addition to the larger crystals, garnet occurs in minute crystals in late sericite fissures and is there frequently associated with arsenopyrite. There are also masses of microscopic garnets which fill spaces between quartz and feldspar. Both occurrences suggest hydrothermal origin.

Williams[24] has recently suggested that the appearance of manganiferous garnet (spessartitic almandite) in the final magmatic extract is an expression of the fact that progressive differentiation increases the MnO/FeO ratio in magmas. This becomes apparent after differentiation has reduced the MgO/FeO ratio almost to the elimination of MgO.

The remaining Fitchburg minerals are noted briefly below.

QUARTZ. Occurs abundantly in the larger pegmatites moulding earlier minerals. It is invariably massive and of a purplish-brown colour, which Holden[25] attributes to silicon, set free by the disintegration of silica under the influence of radioactive substances. Although fairly clear and free from inclusions, it is internally much shattered.

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[24] Williams, G. T. A granite-schist contact in Stuart Island, New Zealand: Title of paper read before the Geological Society of London, December 6th, 1933. Not yet published.

Biotite. Confined to the "Type I" veinlets where it occurs in plates 1–2 cms. across. The refractive indices are: $\alpha=1.640$ β and $\gamma=1.645$, and suggest siderophyllite.

Muscovite. Found most abundantly in the beryl pegmatite where it is grown upon, and may possibly replace, feldspar. It occurs in pinkish bronze plates up to 4 cms. across. Refractive indices: $\alpha=1.562$ $\beta=1.591$, $\gamma=1.595$.

Ilmenite. This mineral occurs occasionally as large platy crystals in the quartz of the "Type II" pegmatites. In addition, corroded ilmenite is found in association with titanite and calcite in the "Type IV" veinlets, while yet a third occurrence is noted in the calcite veins, where the mineral forms delicate hexagonal plates. In the latter, the crystals are somewhat distorted, but measurement shows them to be combinations of $c(0001)$, $r(10\bar{1}1)$, $n(22\bar{4}3)$, and, more rarely $\pi(\bar{1}2\bar{1}3)$.

Titanite. Appears to be wholly confined to the "Type IV" veins, where it occurs massive and in individual crystals up to 2 cms. across. The crystals are simple, tabular, and cinnamon brown in colour. The only forms present are $c(001)$, $n(111)$, and $l(\bar{1}12)$.

Apatite. Very rare, but occasionally occurs embedded in feldspar and associated with almandite in the beryl pegmatite. The mineral occurs in rude hexagonal prisms, 1 to 2.5 cms. in length, and is pale grey to greenish-white in colour. Refractive indices: $\epsilon=1.632$, $\omega=1.634$.

Fluorite. Small light purple to colourless cubes, 0.3 cm. along an edge, occur on the selvages of the calcite veins.

Sulphides. Very small quantities of arsenopyrite, pyrrhotite, chalcopyrite, and molybdenite occur in the tourmaline and beryl-bearing pegmatites, and are there usually associated with the quartz forming the core. A similar occurrence of sulphides in quartz was reported by Warren and Palache[26] in the case of the Quincy pegmatites.

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[25] Holden, E. F., The cause of color in smoky quartz and amethyst: *Amer. Min.*, vol. **10**, p. 224, 1925.

[26] Warren, C. H. and Palache, C. The pegmatites of the riebeckite-aegerite granite of Quincy, Mass., U. S. A.; their structure, minerals, and origin: *Proc. Amer. Acad. Arts & Sci.*, vol. **XLVII**, p. 125, 1911

Arsenopyrite is the most abundant sulphide and occurs both massive and as crystals commonly showing the forms:—

$m(110)$, $q(011)$, $e(101)$, $k(021)$, $t(013)$.

Certain crystals of this mineral from Fitchburg, recently acquired by the Harvard Museum,[27] are somewhat complex and show, in addition to the above, the forms:

$g(111)$, $o(112)$, $i(312)$, $n(012)$, $\phi(023)$, $\tau(031)$, $x(321)$, $B(514)$.

These crystals form a parallel group about 1 cm. in diameter, and are in contact with beryl and quartz in which they leave sharp moulds. The forms $o(112)$, and $B(514)$ were both first found on crystals from Franklin, N. J., and later on crystals from a pegmatite in Newry, Maine.

Polished sections of arsenopyrite show that it is particularly pure and free from intergrowths and inclusions.

Rarely small masses of pyrrhotite occur which, in polished section, furnish excellent examples of supergene alteration to concretionary marcasite. Grains of chalcopyrite are frequently grown upon the pyrrhotite.

Molybdenite is extremely rare but occasionally occurs in fissures in the beryl vein, associated with late sericite and small garnets.

Conclusion

The general tenor of accumulated evidence suggests that pegmatites are by-products of the crystallization of intrusive magmas, and have been derived from the consolidation of the residual, more mobile mother liquor. Such a fundamental premise is entirely acceptable in the case of the Fitchburg pegmatites, for not only do the pegmatitic bodies lie wholly in granite, but the quartz and feldspar which form the bulk of their filling, though much coarser in texture, are similar in character to the quartz and feldspar of the granite itself. Moreover, certain accessory species occurring in the granite, occur also in the pegmatites.

Enquiry into the exact nature of the processes whereby the residual liquors (restmagma) became separated and emplaced presents more difficult problems. In the present instance, the pegmatites occur as apparently isolated lenses and discontinuous stringers, without any obvious connecting channel-ways. Observations on the pipe-like pegmatites associated with the riebeckite-aegerite granite of Quincy, Mass., led Warren and Palache[28] to regard them as "closed-system" pegmatites, which had resulted from the imprisonment, and crystallization in situ, of large bubble-like accumulations of mother-liquor within the granite. In view of the apparent isolation of the lenses, such a theory might prove applicable to the Fitchburg pegmatites. Andersen[29], however, observes that large, apparently isolated, lenses of pegmatite lie outside the granite in certain localities, and he is therefore forced to the conclusion that the material has been introduced through cracks of a capillary fineness which ordinarily escape detection in the field. Another point worthy of consideration is that, at any given time, we only see a very small fraction of a pegmatitic lens, and although it may appear isolated, we cannot be certain that hidden "feeders" do not exist. Observations on the larger (tourmaline type) pegmatites at Fitchburg certainly suggest that they are of the "closed system" type, though in view of Andersen's observation, a definite conclusion is impossible. Their present shape may, at least in part, be due to deformation by external forces acting upon the somewhat mushy, newly consolidated granite. If this were actually the case, it is easy to understand why some of the early-formed crystals are fractured and off-set in the manner described.

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[27] I am indebted to Professor Palache for crystallographic data concerning these crystals.

Possibly the most striking feature of the Fitchburg pegmatites is that their textural features and accessory minerals enable them to be classified into the five very definite and distinct types, which have been described in detail in preceding pages. Evidence regarding the sequence in which the various types were formed is incomplete, but it is known that the biotite veinlets preceded the tourmaline-bearing pegmatites, and that these latter are intersected by the allanite veinlets. These facts, taken in conjunction with mineralogical characters and occurrences at other localities, suggest that the sequence of formation was: (a) the biotite type, (b) the tourmaline type, (c) the beryl type, (d) the titanite type, and (e) the allanite type.

In seeking an explanation of the origin of these contrasted types, it seems impossible to escape the conclusion that they represent successive fractions arising from the progressive crystallization of the mother liquor. Continued crystallization of a magma containing volatile substances normally results in the progressive formation, first of pegmatitic residues, and later, of hydrothermal solutions. With the exception of the allanite stringers, the residues which gave rise to the Fitchburg types, do not appear to have evolved beyond the pegmatitic stage, and evidence of hydrothermal activity, though not entirely wanting, is very meagre.

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[28] Warren, C. H. and Palache, C. *op. cit.*

[29] Andersen, O. Discussions of certain phases of the genesis of pegmatites: *Norske Geol. Tidsskr.*, vol. **XII,** p. 14, 1931.

The various materials constituting the pegmatites are tightly crystallized and present a frozen contact with the enclosing granite. Cavities are absent and there are no signs of extensive hydrothermal replacement. The replacement of tourmaline crystals by quartz appears to be of a magmatic type, and possibly resulted either from the action of "late-stage" magmatic liquors, or from changes of solubility brought about by fluctuations of temperature and pressure. A special feature of the Fitchburg pegmatites is the deuteric replacement of microcline by small masses of albite and albitic plagioclase. This effect is barely noticeable in the biotite veinlets, is moderately developed in the tourmaline type pegmatites, and reaches maximum development in the titanite veinlets. If the various types represent successively derived fractions, as suggested, then the later the fraction, the greater the tendency for this form of deuteric replacement to ensue. Albitization resulting in the production of cleavelandite—though absent at Fitchburg—possibly represents the continued trend of the process at a lower temperature, and on a more extensive scale.

At Fitchburg, only the allanite stringers and calcite veins appear to be of true hydrothermal origin. In places where the former intersect the tourmaline pegmatites, microcline has frequently been replaced by allanite. Sparsely distributed sulphides, and small garnets associated with arsenopyrite in sericite-filled fissures in the beryl-vein, represent minor expressions of hydrothermal activity.

Regarded separately, members of the biotite, tourmaline, and beryl types have resulted from one initial crystallization and, except to the very minor extent cited above have remained unmodified by later hydrothermal agencies. Adopting the classification recently proposed by Landes,[30] the principal tourmaline-bearing members correspond to simple normal granite pegmatites. Graphic granite does not occur at Fitchburg. Andersen,[31] who has studied zoned pegmatites, states that plagioclase-graphic-granite is first deposited, and is followed by microcline-graphic-granite and finally, by quartz and feldspar not intergrown in graphic fashion. Judged by this observation, the Fitchburg pegmatites formed at a somewhat lower temperature than those New England pegmatites showing graphic inter-growths.

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[30] Landes, K. K. Origin and classification of pegmatites: *Amer. Min.*, vol. **18**, p. 96, 1933.

Finally, the pegmatites described in this paper appear to be chiefly of interest in that they tend to reveal the changes occurring in the pegmatitic residues before they assumed the characters of high-temperature hydrothermal solutions. They still remained richly feldspathic, but contained progressively increasing amounts of soda which, prior to complete consolidation, reacted with and replaced the already crystallized microcline.

The author gratefully acknowledges his indebtedness to Professor Palache, whose teaching inspired this present study. He also records his deep gratitude to the Commonwealth Fund of New York City, under whose auspices he was privileged to study in the United States.

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[31] Andersen, O. Discussions of certain phases of the genesis of pegmatites: *Norske Geol. Tidsskr.*, vol. **XII**, p. 27, 1931.

THE CHEMICAL FORMULA AND CRYSTAL SYSTEM OF ALLEGHANYITE*

AUSTIN F. ROGERS, *Stanford University.*

In looking over a thin-section of the alleghanyite-bearing vein from Bald Knob, Alleghany County, N. C., I was impressed with the resemblance of the subhedral crystals of alleghanyite to crystals of chondrodite in metamorphic limestones.

The formula $5MnO \cdot 2SiO_2$ was assigned to alleghanyite by Ross and Kerr.[1] The formula of chondrodite is $5MgO \cdot 2SiO_2 \cdot H_2O$ for the fluorine-free end member. It then occurred to me that the water content of alleghanyite might have been overlooked in the original analysis. Such proves to be the case, for a good closed tube test for water was obtained from the alleghanyite. It seemed reasonable, then, that alleghanyite might be the manganese analogue of chondrodite with the formula $5MnO \cdot 2SiO_2 \cdot H_2O$ or $2Mn_2SiO_4 \cdot Mn(OH,F)_2$. A new analysis has been made and the mineral has been carefully examined in thin-sections. As a result of this study I am convinced that the formula of alleghanyite is $5MnO \cdot 2SiO_2 \cdot H_2O$ and not $5\ MnO \cdot 2SiO_2$ as given by Ross and Kerr. Ross and Kerr went to great pains to show that alleghanyite is not tephroite ($2MnO_2 \cdot SiO_2$), but overlooked its possible relation to other mineral groups.

As will be seen later, alleghanyite is monoclinic and not orthorhombic as Ross and Kerr state.

The specimens on which this study is based were kindly furnished me by Dr. D. F. Hewett of the United States Geological Survey, who collected them at the original locality.

Specimens of the alleghanyite-bearing vein have a banded gneissoid appearance with colorless manganian calcite and reddish alleghanyite. Small black submetallic grains prove to be galaxite. Thin-sections show a small amount of alabandite, a mineral which was overlooked by Ross and Kerr. The alabandite is translucent green in thin fragments and is optically isotropic. It is soluble in hydrochloric acid with the evolution of hydrogen sulfide. The alabandite is readily distinguished from galaxite in thin-sections when examined in reflected light. As noted by Hewett and Rove,[2] alabandite is a widely-distributed mineral in manganese deposits, but has often been overlooked.

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* Paper presented at the fifteenth annual meeting of the Mineralogical Society of America, Rochester, N. Y., December 27, 1934.

[1] *American Mineralogist,* vol. **17,** pp. 9–10, 1932.

[2] *Economic Geology,* vol. **25,** pp. 36–56, 1930.

GEOMETRICAL CRYSTALLOGRAPHY

The alleghanyite occurs in small (usually between 0.3 and 1 mm.) subhedral crystals which are ordinarily somewhat rounded. Most of the crystals are equidimensional with a tendency toward tabular habit (see Figs. 3 and 5). If the alleghanyite is the manganese analogue of chondrodite then the dominant form of many crystals is {001}. It is common to find crystal sections with one well-defined straight edge (see Figs. 3–6). This is the trace of the (001) face. There is occasionally an imperfect cleavage (or parting) trace parallel to this face (see Fig. 3, upper right center).

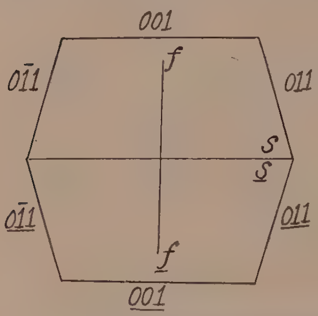

FIG. 1. Section of twinned alleghanyite cut parallel to (100). (*f*=fast ray; *s*=slow ray.)

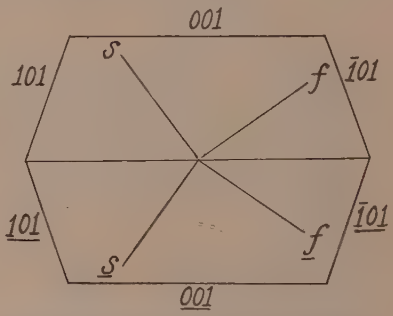

FIG. 2. Section of twinned alleghanyite cut parallel to (010).

Careful search of thin-sections reveals a few sections of euhedral crystals on which approximate measurements have been made. Four or five sections essentially like Fig. 1 were noted. This is interpreted as a section approximately parallel to (100), since it gives parallel extinction to the trace of (001) with the slow ray in the horizontal position. The outlines of the section are traces of the (001), (011), and ($0\bar{1}1$) faces. The angle ($001 \wedge 011$) varies from 73 to 75°. The corresponding angle for chondrodite is $72°21\frac{1}{2}'$. All but one of the measured (100) sections are twins with (001) as the twin-plane. It is possible that in the crystals with sections like Fig. 1 the form present is {111} or even {*hll*} instead of {011}, but this would not change the value of the angle for this particular section. The interzonal angle $[010] \wedge [0\bar{1}1]$ is the same as the interfacial angle $(001) \wedge (011)$.

One measurable section like Fig. 2 was found. This is a twinned crystal cut approximately parallel to (010), for the extinction angle is near the maximum value. The forms are evidently {001}, {101}, and {$\bar{1}$01}. The angle (001 ∧ 101) is about 69°; the corresponding angle for chondrodite is 70°56½′.

The forms {001}, {011}, {101}, and {$\bar{1}$01} are very common for chondrodite and one would expect them to be common for the manganese analogue of chondrodite. The geometrical crystallography of alleghanyite as far as can be ascertained seems to be similar to that of chondrodite. Some of the common forms are the same and the interfacial angles are similar.

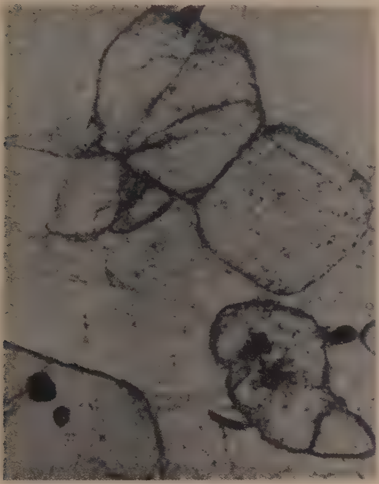

FIG. 3. (×56 diameters.) Subhedral crystals of alleghanyite in a matrix of calcite. The opaque mineral is galaxite.

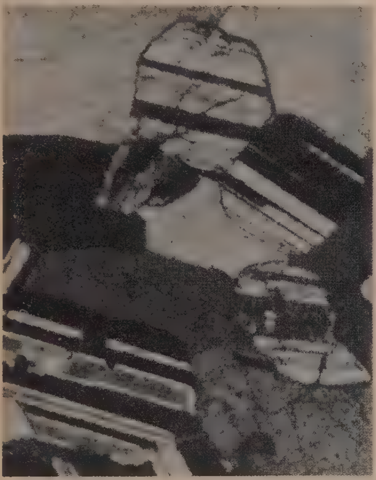

FIG. 4. (×52 diameters.) The same as Fig. 3, but taken with crossed nicols to show the polysynthetic twinning.

The symmetrical section shown in Fig. 2 seems to indicate that alleghanyite is orthorhombic but the oblique extinction proves it to be monoclinic. It will be recalled that chondrodite is unusual in that the angle β between the *a*- and *c*-axes is 90°. The probability is that β is also 90° or at least near 90° in alleghanyite.

A great majority of the alleghanyite crystals are twinned as was emphasized by Ross and Kerr. The twinning is usually polysynthetic, but frequently with only a few lamellae, often a single twin-seam. The twin-lamellae are broader and not as numerous as in the average plagioclase section. The twinning is remarkably like that shown in thin-sections of chondrodite; it was this observation that led to the discovery that alleghanyite is the manganese analogue of chondrodite. The twin-plane is taken as (001) to correspond to the common twin-plane of chondrodite. The photomicrographs of Figs. 4 and 6 give a good idea of the twinning in alleghanyite.

A few sections of peculiar composite twins of alleghanyite were observed. These are illustrated by Figs. 7 and 8. Only one of these sections is oriented so as to give an accurate measurement of interfacial angles but there seems to be no doubt as to their interpretation. In each of these, two different twin-laws are exemplified. The polysynthetic twinning in each case is parallel to {001}. In Fig. 7 the reëntrant twinning is (105). The angle (001 $\wedge \underline{001}$) is about 61°; the calculated angle for chondrodite twinned on (105) is 60°8′ (2×30°4′, since 001 $\wedge$ 105 = 30°4′). The extinction angle in the section is about 35°, which is the maximum for alleghanyite; hence the section is parallel to (010). The section shown in Fig. 8 is equally inclined to the twin-plane but it is not parallel to (010), as the extinction angle is only 20°. The angle (001 $\wedge \underline{001}$) is equal to about 68°. In this section the twin-plane must be (305). The calculated interfacial angle (001 $\wedge \underline{001}$) for chondrodite twinned on

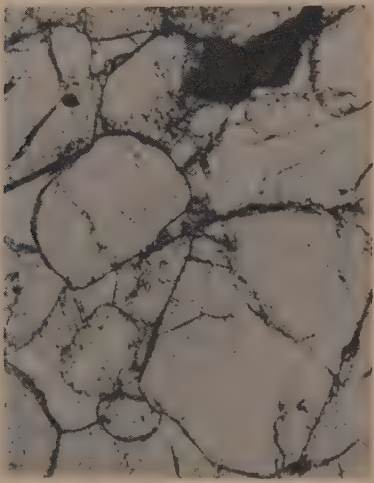

FIG. 5. (×56.) Subhedral crystals of alleghanyite with opaque galaxite.

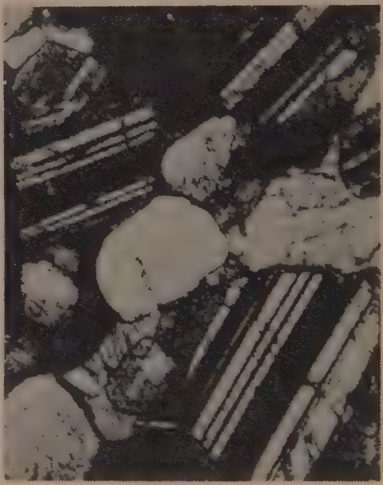

FIG. 6. (×52.) The same as Fig. 5, but taken with crossed nicols to show the polysynthetic twinning.

(305) is 59°52′. The divergence in value of this angle is due to the fact that the section is not parallel to (010).

Twins with (105) and (305) as twin-planes combined with polysynthetic (001) twinning are very characteristic of chondrodite.[3,4] The presence of twinning according to the three twin-laws (001), (105), and (305) known for chondrodite, on alleghanyite is strong corroboration of the view that alleghanyite is the manganese analogue of chondrodite.

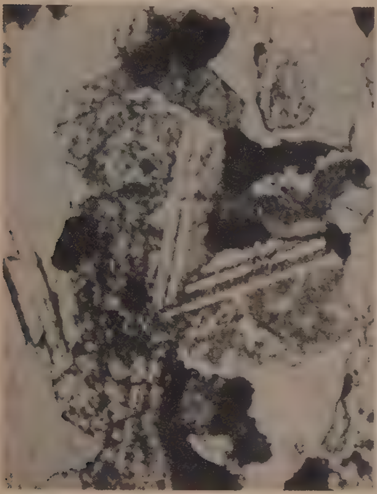

FIG. 7. (×56.) Composite twin of alleghanyite taken with crossed nicols. The twin-planes are (001) and (105).

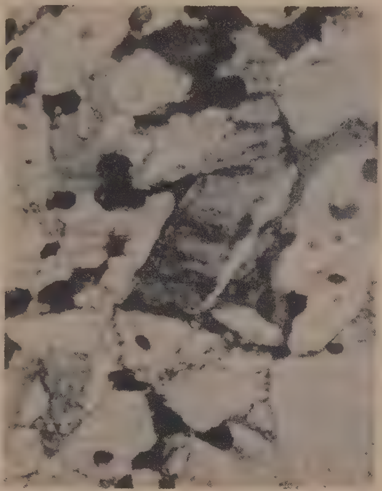

FIG. 8. (×56.) Composite twin of alleghanyite taken with crossed nicols. The twin-planes are (001) and (305).

In twins of chondrodite, twin-laws according to (105) and (305) are often difficult to distinguish from each other, but in this particular case it is easy to make the distinction on account of the presence of polysynthetic (001) twinning.

STRUCTURAL CRYSTALLOGRAPHY

Powder photographs of alleghanyite were kindly made for me by my colleague, Dr. J. L. Hoard of the Chemistry Department, and, for comparison, also powder photographs of chondrodite from

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[3] See Rosenbusch-Mügge, *Mikroskopische Physiographie der petrographisch-wichtigen Mineralien*, Band I, 2d Hälfte, p. 445, *Stuttgart*, 1927.

[4] See also Goldschmidt, *Atlas der Krystallformen*, Band IV, Tafel 103, Fig. 103, *Heidelberg*, 1918.

leads from A to B, not from B to A. Thus A cannot be dispensed with.

We have reached the conclusion; the decision is:

System A is to be retained, B set aside.

RETROSPECT AND HISTORY

The arguments against B, particularly 1–4, are so conclusive, that it appears incomprehensible that so large a proportion of our mineralogical teachers, among them distinguished, even prominent men, have decided in favor of B.

We will try to trace this historically.

The thirty-two classes were founded by A. Gadolin (1867), and introduced to wider circles by P. Groth (1895), who says:[9]

> "The systematic treatment of crystallography developed above proceeded from the simple crystal forms, *i.e.* those with the lowest grade of symmetry, and, by addition of further symmetry elements, gradually reached the most symmetrical of the thirty-two classes, each of which represents an independent unity characterized by definite symmetry relations.
>
> "The gathering of certain symmetry classes into one group (crystal system), which was used for ready survey, rests on purely practical considerations, and is, in a certain sense, even arbitrary. These groups constitute the foundation of the earlier crystallographic presentations."

At that time P. Groth stood in high esteem and others followed him. Respected mathematicians (Schönfliess) consolidated the system. One admired mathematics which was able to review a rich natural science (crystallography) and give it a system, without having concerned itself in detail with crystals by way of natural research. One forgot that crystallography is a natural science and not a chapter of mathematics.

Crystals cannot be understood, no more than lizards or frogs, or classified according to their characters, without studying them in detail. If we classify without detailed study we go astray, for Nature is always right.

We have had this case once before in crystallography. It was believed that crystal forms were to be seen in the regular bodies of stereometry; this was true in the case of the tetrahedron, the cube, the octahedron, and the rhombic dodecahedron, but failed with the pentagonal dodecahedron. That way was abandoned, and the same should be done again to-day.

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[9] *Physikalische Kristallographie*, Ed. III, p. 523, **1895** (*trans.*).

of the humite group. The diffraction patterns indicate that alleghanyite is related to the humite group in some way. The chemical analysis given later proves that alleghanyite is isomorphous with chondrodite.

Ross and Kerr point out the close similiarity of the diffraction patterns of alleghanyite and tephroite. Now there is a reasonable explanation of this similarity and of the practical identity of some of the lines. Taylor and West[6] have shown that chondrodite is made up of double layers of Mg_2SiO_4 alternating with one layer of $Mg(OH,F)_2$. So that if tephroite bears the same relation to alleghanyite that forsterite does to chondrodite, as seems probable, one would expect the diffraction pattern of alleghanyite to be similar to that of tephroite.

Optical Crystallography

Most of the subhedral alleghanyite crystals show polysynthetic twinning when examined in thin-sections between crossed nicols (see Figs. 4 and 6). The twin-plane is (001) since alleghanyite is in all probability isomorphous with chondrodite. Some sections give a negative optic-axis interference figure with a rather large axial angle.[7]

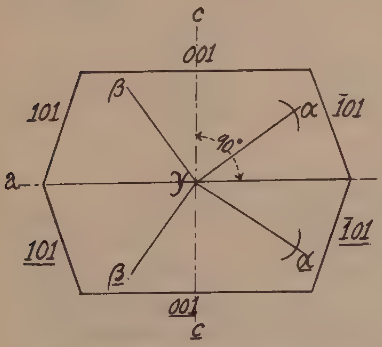

Fig. 11. Optical orientation of alleghanyite. This represents a twinned crystal cut parallel to (010). $a\wedge\alpha = -35°$, $b=\gamma$, $c\wedge\beta=-35°$. Axial plane ⊥ (010). Optic sign (−).

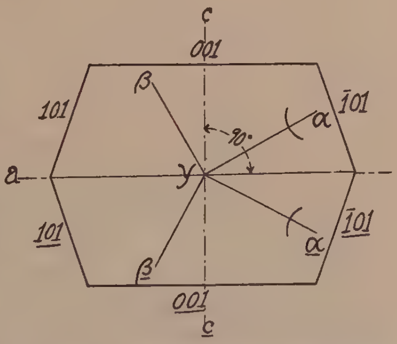

Fig. 12. Optical orientation of chondrodite. This represents a twinned crystal cut parallel to (010), $a\wedge\alpha = -26$ to $-31°$, $b=\gamma$, $c\wedge\beta=-26$ to $-31°$. Axial plane ⊥ (010). Optic sign (+).

Most of the twinned sections show oblique extinction and the maximum extinction angle measured from the trace of the twin-plane (001) is about 35°. Ross and Kerr give this angle as 22°, but in various sections many values higher than 22° were found, with the maximum at 35°. The extinction direction 35° from the trace of (001) is the faster ray. Other sections twinned on (001) have parallel or nearly parallel extinction with the trace of the twin-plane parallel to the slower ray. The optical orientation of alleghanyite, then, is as shown in Fig. 11. This is similar to the optical orientation of chondrodite (Fig. 12) except that the latter mineral is optically positive.

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[6] *Proc. Roy. Soc.* (*London*), vol. **117A**, pp. 517–532, 1928.

[7] According to Ross and Kerr, $2V=72°$.

The optical properties prove beyond any doubt that alleghanyite is monoclinic and not orthorhombic. The statement of Ross and Kerr, "The bilateral symmetry of the twinning in two perpendicular planes indicates that the mineral [alleghanyite] is orthorhombic," is not at all convincing. If alleghanyite is orthorhombic, the geometrical orientation would have to be something like that shown in Fig. 13. The combination of forms would be $\{h0l\}$, $\{\bar{h}'0l'\}$ and $\{\bar{h}''0l''\}$ as given in the figure. The axes of reference must be parallel to extinction directions and if the mineral is orthorhombic they must either all be axes of 2-fold symmetry or there must be two planes of symmetry with a 2-fold axis at their intersection. It is clear, therefore, that alleghanyite cannot belong to any of the three crystal classes of the orthorhombic system.

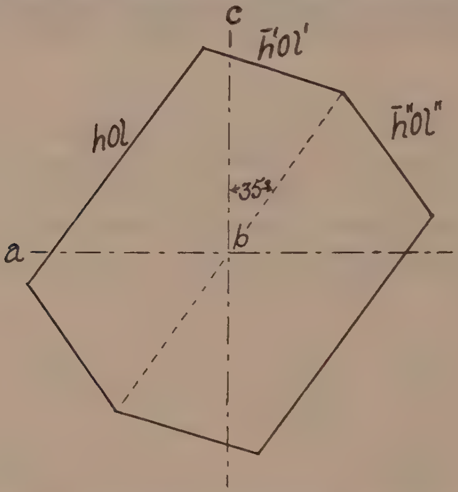

FIG. 13. The geometrical orientation of alleghanyite provided it is orthorhombic.

Chemical Composition

In view of my belief that the chemical formula of alleghanyite is different from the one given by Ross and Kerr, I thought it advisable to have a new chemical analysis made. Accordingly, a sample was prepared by a combination of hand picking, electromagnetic separation,[8] and separation by Clerici solution. The sample was not quite pure, but contained small amounts of calcite and galaxite with a little alabandite.

The analysis was made by Dr. R. B. Ellestad of the Rock Analysis Laboratory of the University of Minnesota with the following results (column I):

	I	II	Galaxite	Calcite	Alabandite	Alleghanyite	
SiO_2	22.75	.3732				3732	3750
TiO_2	0.15	.0018				18	
Al_2O_3	0.75	.0073	73				
Fe_2O_3	0.73	.0046	46				
CaO	1.34	.0239		239			
MgO	0.71	.0176				176	9399
MnO	67.85	.9566	46 . . 73	197	27	9223	
H_2O	2.56	.1422				≎(OH) 2841	2998
F	0.30	.0157				157	
CO_2	1.92	.0436		239 . . 197			
S	0.11	.0021			21		
	99.17						
Less O≎F+S=	0.35						
Total	98.82						

The molecular ratios are given in column II. Assuming the formula of galaxite to be $Mn(Al,Fe)_2O_4$, all the alumina and ferric oxide and equivalent amounts of manganous oxide are assigned to galaxite. The sulfur is allotted to alabandite. All the lime and an amount of manganous oxide equivalent to the rest of the carbon dioxide is assigned to the manganian calcite. The remainder of the manganous oxide plus the magnesia is left for alleghanyite. The titania[9] is combined with the silica. The water is calculated as hydroxyl in order that the fluorine may be combined with it.

The ratios, then, are 9399 MnO:3750 SiO_2:2998(OH,F). Since the formula of the manganese analogue of chondrodite is $4MnO \cdot 2SiO_2 \cdot Mn(OH,F)_2$ the ratios for alleghanyite may be expressed as: $7500MnO \cdot 3750SiO_2 \cdot 1470Mn \cdot 2998(OH,F)$, which is equivalent to $4(1875)MnO \cdot 2(1875)SiO_2 \cdot 1(1485)Mn(OH,F)_2$ or $4MnO \cdot 2SiO_2 \cdot 0.79Mn(OH,F)_2$.[10] This is very close to $4MnO \cdot 2SiO_2 \cdot 1Mn(OH,F)_2$. There is a slight deficiency of combined hydroxyl and fluorine, which is probably due to inaccuracy in the fluorine determination. It will be noted that the summation of the analysis is rather low.

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[8] The galaxite has a greater magnetic susceptibility than alleghanyite.

[9] It will be recalled that the so-called "titanolivin" is a titanian clinohumite; it is therefore not surprising to find titanium in alleghanyite.

This new analysis ($5MnO:2SiO_2$) confirms the $5MnO:2SiO_2$ ratio of the analyses given by Ross and Kerr. But the presence of water and fluorine in the mineral establishes the formula as $2Mn_2SiO_4 \cdot Mn(OH,F)_2$, which together with the crystallographic properties proves that alleghanyite is isomorphous with chondrodite. The theoretical composition of $2Mn_2SiO_4 \cdot Mn(OH)_2$ is $MnO = 71.90$, $SiO_2 = 24.45$, $H_2O = 3.65$; and for $2Mn_2SiO_4 \cdot MnF_2$ it is $MnO = 71.32$, $SiO_2 = 24.25$, $F = 7.62$; $\text{Total} = 103.21 - 3.21 (O \Bumpeq F) = 100.00$.

SUMMARY OF OBSERVATIONS

The various arguments in support of the view that alleghanyite is the manganese analogue of chondrodite may be summarized thus:

1. Alleghanyite is monoclinic with $\beta(a \wedge c)$ either equal or nearly equal to 90° and with observed forms the same as some of the common forms of chondrodite.

2. The polysynthetic twins after (001) and the composite twins after (001) and (105) and after (001) and (305) are remarkably like those of chondrodite. The three twin-laws [(001), (105), and (305)] known for chondrodite are also the twin-laws for alleghanyite.

3. The diffraction pattern of alleghanyite is remarkably similar to that of chondrodite (or other member of the humite group).

4. The diffraction pattern of alleghanyite is much like that of tephorite, as it should be, since the internal structures of the

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[10] 1485 is the average of 1470 and one-half of 2993.

analogous pair of minerals, chondrodite and forsterite, have much in common.

5. The $5MnO:2SiO_2$ ratio of alleghanyite corresponds to the $5MgO:2SiO_2$ ratio of chondrodite.

6. A small amount of titania recalls the existence of titanium-bearing clinohumite ("titanolivin").

7. The presence of water (hydroxyl) and fluorine in alleghanyite is matched by the presence of water and fluorine in chondrodite.

8. The ratios obtained from a new chemical analysis of alleghanyite agree better with the formula $2Mn_2SiO_4 \cdot Mn(OH,F)_2$ than they do with any other formula.

In view of the foregoing facts, there seems to be no doubt that alleghanyite is a monoclinic mineral with the formula $2Mn_2SiO_4 \cdot Mn(OH,F)_2$ and hence is isomorphous with chondrodite, $2Mg_2SiO_4 \cdot Mg(OH,F)_2$.

SUMMARY OF CORRECTED DATA FOR ALLEGHANYITE

Formula: $2Mn_2SiO_4 \cdot Mn(OH,F)_2$
Sp. Gr.: 4.020
Crystal system: Monoclinic; $\angle\beta =$ or *ca.* $= 90°$
Forms: $\{001\}$, $\{011\}$, $\{101\}$, $\{\bar{1}01\}$
Twin-Laws: $\{001\}$, $\{105\}$, $\{305\}$
Indices of Refraction: $n_\alpha = 1.756$, $n_\beta = 1.780$, $n_\gamma = 1.792$
Birefringence: $n_\gamma - n_\alpha = 0.036$
Optical Character: (−)
Optic Axial Angle: $2V = 72°$
Optical Orientation: $a \wedge \alpha = -35°$, $b = \gamma$, $c \wedge \beta = -35°$
Optic Axial Plane: $\perp(010)$.

THE UNIT CELL AND SPACE GROUP OF REALGAR

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Abstract

Realgar from Allchar, Macedonia, has been studied by the Weissenberg method. A new orientation is chosen by taking the *a*-axis in Goldschmidt's [101] direction; this gives the simplest cell. The cell characteristics are:

	absolute	ratio
$a=$	9.27Å	.6878
$b=$	13.50	1.
$c=$	6.56	.4858
$\beta=$	73°227′	
$Z=$	16 formula weights per cell	

Space group: C_{2h}^5, $P2_1/n$.

The monoclinic holohedral nature of realgar has been confirmed by purely *x*-ray methods.

The extremely unfavorable geometry of the space group prevents an immediate, complete determination of the structure.

Introduction

So far as the writer is aware, no study of the crystal structure of realgar has been published. The writer's investigation has proceeded to a unique determination of the general geometry of the cell of this mineral. It has been thought desirable to record the results to this point, inasmuch as they form a firm groundwork for further structural study, the pursuit of which must rest on somewhat less secure reasoning because of the extremely unfavorable geometry of the space-group.

Material and Method

The investigation was carried out on realgar from Allchar, Macedonia. The morphology of this particular material has received a thorough study by Goldschmidt,[1] who also furnished the following chemical analysis:

	found	calculated
S	30.55	29.91
As	69.57	70.09
	100.12	100.00

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[1] Goldschmidt, V., Realgar von Allchar in Macedonien: *Zeit. Krist.*, vol. **39**, pp. 113–121, 1904.

The material is evidently nearly ideal AsS, but with a slightly low As:S ratio, corresponding to an empirical formula $As_{1.000}S_{1.028}$.

Small, well developed crystals of this material were studied by the Weissenberg method. Nearly equi-dimensional crystals of something less than ½ millimeter diameter were completely bathed in an unfiltered beam of CuK radiation of about one millimeter cross sectional diameter.

UNIT CELL

The Weissenberg photographs have been studied, in the main, by the simple method of reciprocal lattice line curve-sketching directly on the original film,[2] but the actual reciprocal lattice has been reconstructed for the *b*-axis photographs. A study of these, together with Z measurements on pinacoid reflections, indicates that the simplest cell results by the choice of a new *a* axis in Goldschmidt's [101] direction. The geometry of the unit chosen by this Weissenberg study, and checked by rotation photographs, is given in comparison with Goldschmidt's elements in table I.

TABLE I

X-ray Data			Goldschmidt's Data	
Designation, Simplest Cell Axes	Dimension	Axial Ratio	Axial Ratio	Designation, Goldschmidt's Axes
a	9.27Å	.6875	.6878	[101]
b	13.50	1.	1.	*b*
c	6.56	.486	.4858	*c*
[101]			.7203	*a*
β			73°27′	$c\wedge[101]$
$c\wedge[101]$			66°15.6′	$\mu(=\beta$, Dana)
(Cell volume)				
V	788 Å³			

The ideal formula weight of AsS is 106.9. The analysis given by Goldschmidt of the Allchar material indicates an empirical formula $AsS_{1.028}$. If the additional sulfur proxies for an arsenic deficiency, this is equivalent to $\left|\begin{matrix}As_{.986}\\ S_{.014}\end{matrix}\right|S$. which has a formula weight of 106.3. This differs from the ideal value by the order of half a per cent. The number of formula weights per unit cell, Z, is given by the relation:

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[2] Buerger, M. J., The Weissenberg reciprocal lattice projection and the technique of interpretating Weissenberg photographs: *Zeit. Krist.*, vol. **88,** pp. 356–380, 1934.

$$\text{measured density} = \frac{\text{cell mass}}{\text{cell volume}} = \frac{Z \times \text{formula wt}}{\text{cell volume}}.$$

With Dana's density value for realgar, this becomes:

$$3.56 = \frac{Z \times (\text{formula wt.}) \times 1.64 \times 10^{-24}}{788 \times 1.64 \times 10^{-24}}.$$

Use of the ideal formula weight leads to Z = 16.00, while assuming the excess sulfur, indicated by the analysis, proxies for arsenic, leads to Z = 16.09 formula weights per unit cell. Lack of coordination and precision in the measurements renders the difference between these two values non-diagnostic.

SPACE GROUP

Equatorial Weissenberg photographs were taken for rotations about the *a*, *b*, *c*, and [101] axes, together with first and second layer photographs for the *b*-axis. All of these have been unequivocally indexed by the simple method of reciprocal lattice line curve sketching, directly on the film (plus reconstructing the *b*-axis, zero and first levels). A catalog of the resulting reflections is given in table II.

TABLE II

CATALOG OF REFLECTIONS

Indices are referred to new axes; to transform to Goldschmidt's axes, add *l00* to each index listed. Dashes indicate assured absences.

b-axis, 1st layer											
017	—										
016	116	—	316	416							
015	—	215	315	415	515						
014	114	214	314	—	514	614	714				
013	113	213	313	—	513	—	713	813			
012	112	212	312	412	512	612	712	812	912		
011	—	211	311	411	511	611	711	811	911	10.1.1	
	110	210	310	410	510	610	710	810	910	10.1.0	
	$\bar{1}11$	$\bar{2}11$	$\bar{3}11$	—	$\bar{5}11$	—	—	$\bar{8}11$	$\bar{9}11$	$\overline{10}.1.1$	—
	$\bar{1}12$	$\bar{2}12$	$\bar{3}12$	$\bar{4}12$	$\bar{5}12$	$\bar{6}12$	$\bar{7}12$	$\bar{8}12$	$\bar{9}12$	$\overline{10}.1.2$	$\overline{11}.1.2$
	$\bar{1}13$	$\bar{2}13$	$\bar{3}13$	$\bar{4}13$	$\bar{5}13$	$\bar{6}13$	—	$\bar{8}13$	$\bar{9}13$	—	
	$\bar{1}14$	$\bar{2}14$	$\bar{3}14$	$\bar{4}14$	$\bar{5}14$	$\bar{6}14$	$\bar{7}14$	$\bar{8}14$	$\bar{9}14$	$\overline{10}.1.4$	
	$\bar{1}15$	$\bar{2}15$	$\bar{3}15$	$\bar{4}15$	$\bar{5}15$	$\bar{6}15$	$\bar{7}15$	$\bar{8}15$	$\bar{9}15$		
	$\bar{1}16$	$\bar{2}16$	$\bar{3}16$	$\bar{4}16$	$\bar{5}16$	$\bar{6}16$	$\bar{7}16$	$\bar{8}16$			
	—	$\bar{2}17$	$\bar{3}17$	$\bar{4}17$	$\bar{5}17$	$\bar{6}17$	$\bar{7}17$				

TABLE II (*Continued*)

b-axis equator											
—	107	—									
006	—	206	—	406	—						
—	—	—	305	—	505	—					
—	—	—	—	404	—	604	—				
—	103	—	303	—	503	—	703	—			
002	—	202	—	402	—	602	—	802	—		
—	101	—	301	—	501	—	701	—	901	—	
	—	200	—	400	—	600	—	800	—	10.0.0	—
	$\bar{1}01$	—	$\bar{3}01$	—	$\bar{5}01$	—	$\bar{7}01$	—	$\bar{9}01$	—	—
	—	$\bar{2}02$	—	$\bar{4}02$	—	$\bar{6}02$	—	$\bar{8}02$	—	$\overline{10}.0.2$	—
	$\bar{1}03$	—	$\bar{3}03$	—	$\bar{5}03$	—	$\bar{7}03$	—	$\bar{9}03$	—	$\overline{11}.0.3$
	—	$\bar{2}04$	—	$\bar{4}04$	—	—	—	$\bar{8}04$	—	$\overline{10}.0.4$	
	$\bar{1}05$	—	—	—	—	—	$\bar{7}05$	—	$\bar{9}05$	—	
	—	$\bar{2}06$	—	$\bar{4}06$	—	$\bar{6}06$	—	$\bar{8}06$	—		
	$\bar{1}07$	—	$\bar{3}07$	—	$\bar{5}07$	—					

TABLE II (*Continued*)

a-axis equator							
	—	002	—	—	—	006	—
—	011	012	013	014	015	016	017
020	021	022	023	024	025	026	027
—	031	032	033	034	—	036	037
040	041	042	043	044	—	046	047
—	051	—	053	054	055	056	057
060	061	062	063	064	065	066	067
—	071	072	073	—	075	076	077
080	081	082	083	084	085	086	
—	091	092	093	094	095	096	
0.10.0	0.10.1	0.10.2	0.10.3	0.10.4	0.10.5	0.10.6	
—	0.11.1	—	0.11.3	—	0.11.5		
0.12.0	0.12.1	0.12.2	0.12.3	0.12.4			
—	0.13.1	—	0.13.3	0.13.4			
0.14.0	0.14.1	—	0.14.3				
—	0.15.1	0.15.2	0.15.3				
0.16.0	0.16.1						

TABLE II (*Continued*)

c-axis equator																
	—	020	—	040	—	060	—	080	—	0.10.0	—	0.12.0	—	0.14.0	—	0.16.0
—	110	120	130	140	150	160	170	180	190	1.10.0	1.11.0	1.12.0	—	1.14.0	1.15.0	1.16.0
200	210	220	230	240	250	260	—	280	290	2.10.0	2.11.0	2.12.0	—	—	—	
—	310	320	330	340	350	360	370	380	—	3.10.0	—	3.12.0	3.13.0	3.14.0	3.15.0	
400	410	420	430	440	450	460	470	480	—	4.10.0	—	4.12.0	4.13.0	4.14.0	4.15.0	
—	510	520	530	540	550	560	570	580	590	—	—	5.12.0	5.13.0	5.14.0		
600	—	620	—	640	—	—	670	580	690	6.10.0	6.11.0	—	6.13.0			
—	710	720	730	—	750	760	770	780	—	—	7.11.0	7.12.0				
800	810	820	830	840	850	860	870	880	890	8.10.0						
—	910	920	930	940	950	960	970	980	990							
—	10.1.0	—	10.3.0	—	10.5.0	—										

The Weissenberg photographs indicate a centro-symmetrical point group C_2^h, which confirms the monoclinic nature of realgar as deduced from morphological studies.

There are no systematic absences in the list of general, *hkl*, reflections, thus eliminating the body-centered monoclinic lattice, Γ_m', by reflections actually appearing. The primitive nature of the cell is confirmed by the identity of patterns of the *b*-axis first and second layer photographs. This leaves for consideration only the simple monoclinic lattice, Γ_m, upon which are based the space groups, C_s^1, C_s^2; C_2^1, C_2^2; C_{2h}^1, C_{2h}^2, C_{2h}^4, C_{2h}^5. The catalog of reflections plainly indicates the systematic absences:

$h0l$ when $h+l$ is odd
$0k0$ when k is odd.

These characteristics pertain only to C_{2h}^5 of the uneliminated list. This incidentally establishes the holohedral character of realgar by *x*-ray means, by elimination of lower symmetry space groups and therefor the point-groups upon which they are based.

Space group C_{2h}^5 is shown in figure 1. It is composed entirely of screw axes and glide planes. With the choice of unit adopted here, the orientation is indicated by the symbol, $P2_1/n$. This is not the conventional orientation, and the coordinates of equivalent positions are therefor not the ones usually listed in reference books. Coordinates referred to the orientation adopted here are given in table III.

Table III

Coordinates of equivalent positions of space group C_{2h}^5 referred to new realgar axes, orientation $P2_1/n$.

Equipoint designation	Coordinates
4	$[[xyz]]; [[\bar{x}\bar{y}\bar{z}]]; [[\frac{1}{2}+x, \frac{1}{2}-y, \frac{1}{2}+z]]; [[\frac{1}{2}-x, \frac{1}{2}+y, \frac{1}{2}-z]]$
2_a	$[[000]]; [[\frac{1}{2}\frac{1}{2}\frac{1}{2}]]$
2_b	$[[\frac{1}{2}00]]; [[0\frac{1}{2}\frac{1}{2}]]$
2_c	$[[00\frac{1}{2}]]; [[\frac{1}{2}\frac{1}{2}0]]$
2_d	$[[\frac{1}{2}0\frac{1}{2}]]; [[0\frac{1}{2}0]]$

POSSIBLE ARRANGEMENTS

Because of the low internal symmetry of C_{2h}^5, the general position contains only four equipoints, and the only special positions

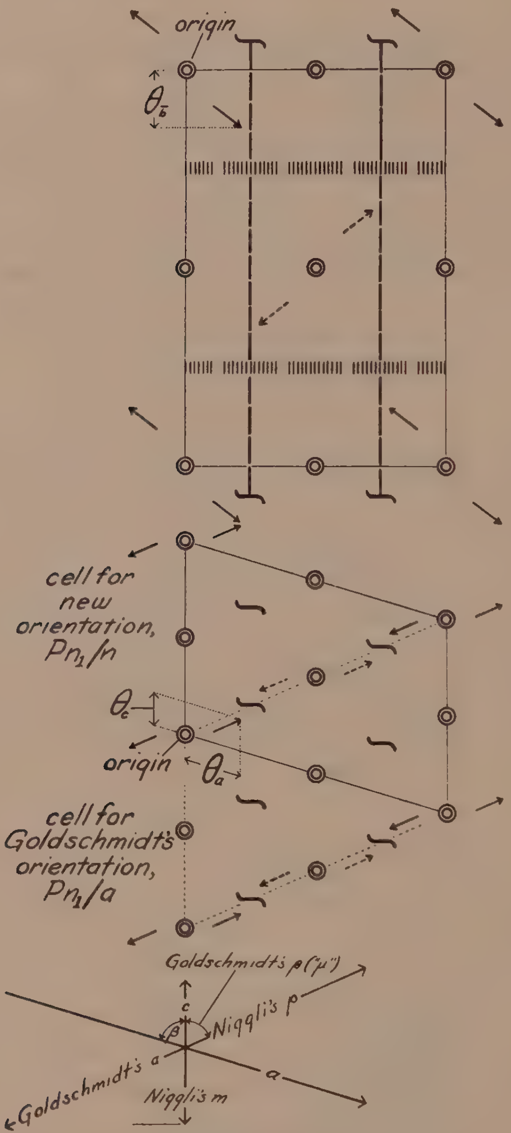

FIG. 1. The space group of realgar, showing the relations between the cell based on the new orientation, the cell based on Goldschmidt's orientation, and Niggli's space group coordinate directions. Double circles are symmetry centers; heavy dashed lines and "S's" are two-fold screw axes; broken ribbons are glide planes with components $a/2+c/2$ for the cell based on the new orientation, or $a/2$ for the cell based on Goldschmidt's orientation. The small full arrows represent molecules associated with symmetry centers on the zero levels, small dotted arrows molecules associated with symmetry centers on the halving levels.

are four 2-fold sets of symmetry centers. Sixteen formula weights of AsS, or 16 As and 16 S must be placed in this cell. Accordingly, there must be several kinds of each atomic species. The possible arrangements are given in table IV. The list is imposing. Of the twenty-one kinds of arrangements possible for realgar, the very simplest must be determined by fixing fifteen parameters, five at a time. The least simple requires the fixing of twenty-four parameters, eight at a time. A unique determination of the structure by customary formal methods is, therefor, out of the question.

TABLE IV

POSSIBLE ARRANGEMENTS FOR REALGAR

Combination designation	As								S								Parameters
1	2_a	2_b	2_c	2_d			4	4					4	4	4	4	18
2	2_a	2_b				4	4	4			2_c	2_d		4	4	4	15
3	2_a		2_c			4	4	4		2_b		2_d		4	4	4	15
4	2_a			2_d		4	4	4		2_b	2_c			4	4	4	15
5		2_b	2_c			4	4	4	2_a			2_d		4	4	4	15
6		2_b		2_d		4	4	4	2_a		2_c			4	4	4	15
7			2_c	2_d		4	4	4	2_a	2_b				4	4	4	15
8	2_a	2_b				4	4	4					4	4	4	4	18
9	2_a		2_c			4	4	4					4	4	4	4	18
10	2_a			2_d		4	4	4					4	4	4	4	18
11		2_b	2_c			4	4	4					4	4	4	4	18
12		2_b		2_d		4	4	4					4	4	4	4	18
13			2_c	2_d		4	4	4					4	4	4	4	18
14					4	4	4	4	2_a	2_b	2_c	2_d			4	4	18
15					4	4	4	4	2_a	2_b				4	4	4	21
16					4	4	4	4	2_a		2_c			4	4	4	21
17					4	4	4	4	2_a			2_d		4	4	4	21
18					4	4	4	4		2_b	2_c			4	4	4	21
19					4	4	4	4		2_b		2_d		4	4	4	21
20					4	4	4	4			2_c	2_d		4	4	4	21
21					4	4	4	4					4	4	4	4	24

The study of the realgar structure is being continued, and it is hoped that a complete structure will be published shortly.

AN AMAZONITE APLITE DIKE FROM LABRADOR

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Introduction

While carrying on geological reconnaissance work in Labrador a small dike of unusual chemical and mineralogical composition was encountered by the writer at Long Tickle. Its exact location is difficult to determine, due to the poor charting of that section of coast. Judging by a sketch plan of the Adlavik region[1] found at the Newfoundland Crown Lands Office in St. John's some time after the region was visited, it lies in latitude 55°3′N. and longitude 58°46′W. on the south shore of the northern Adlavik Island, about a mile east of Maconet Bay.

Field Characters

The dike is five feet wide and strikes in a northerly direction, with steep easterly dip. No variation in size or attitude was observed, but the exposed portion of the dike was not over several hundred yards long.

The wall rock is a coarse grained, light pink to gray syenite, showing foliated zones. For a foot or so on each side of the dike the mafic constituents of the wall rock have been changed into red-brown mica.

The margins of the dike are sharply defined. Judging by the curvature of foliation in the wall rock near the dike, and the displacement of a narrow foliated zone which the dike cuts, it has been injected into a fault plane along which the west wall has been displaced several feet northward.

The dike rock is fine grained and of a very pale greenish color. It contains some 10% of amazonite phenocrysts and a little brownish mica in small flakes. It is foliated about parallel to the walls. Close examination seems to show a linear arrangement of the constituents dipping about 60° in a northerly direction, and directed slightly towards the west wall of the dike, instead of being exactly parallel to it.

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[1] *Sketch Plan of Adlavik Region*, rivers surveyed by Mr. W. J. James, and sketch of coast and islands by W. T. Grenfell ex Yacht "Jeanette," August 1916.

Microscopic Characters

Under the microscope the rock is seen to be made up of amazonite, albite, and quartz, with accessory mica, topaz, fluorite, apatite, magnetic yellow sulfide, and perhaps rutile or zircon. Table I shows the proportions of these minerals as determined by measurement of grains in portions of the rock powder separated with heavy liquids, the sulfide being isolated from the heavy portion by a permanent magnet.

The amazonite in part has the optical properties of microcline. However, in some grains the optic axial angle is undoubtedly positive. This would indicate that the amazonite is in part isomicrocline. In the isomicrocline 2V appears to vary from a minimum of 75° perhaps to 90°. Efforts to correlate the optical and crystallographic orientation in this mineral were not satisfactory, but it seems to differ from normal microcline only by a shifting of the primary optic axes towards c. The refractive indices of the two minerals are very similar. There does not seem to be any great predominance of either mineral in the thin section, but the two could not be separated on a quantitative basis.

In thin section the amazonite is so abundant that without the analyzer the rock shows a nearly continuous matrix of this mineral with rounded grains of quartz and albite, and flakes of mica inset in it. With the analyzer it is seen to be made up of rounded, interlocking grains averaging 0.5 mm. in diameter with various orientations. Occasional irregular grains 4 mm. long are embedded in the matrix of smaller grains. Most of the grains show a well developed grating structure but twinning may be entirely absent. Polysomatic textures occur.

The albite has indices of refraction less than balsam, indicating practically complete absence of anorthite molecules. Twinning is not uncommon. It occurs as irregular, rounded grains up to 0.8 mm. long, some with a tendency towards blocky crystal outlines. It may cut into flakes of mica and grains of amazonite rather deeply. A small amount of the mineral also occurs as spindles of microperthite 0.005 mm. wide in the amazonite. They appear to lie parallel to the crystallographic *c* axis and make up only an insignificant proportion of the areas of amazonite.

The quartz also occurs in small rounded grains, occasionally with slight development of crystal outlines. It may cut into the feldspars and mica. Some grains show anomalous biaxial character to a slight degree, and strain shadows when rotated under crossed nicols.

The optical properties of the mica are in accordance with those given by O. Mügge for zinnwaldite.[2] It occurs as flakes up to 1.15 mm. long. They are often of irregular outline, being cut into by the other minerals of the rock, and occasionally sending small projections into them.

In the topaz 2V is 65°, β is close to 1.615 and the birefringence is about 0.01. It occurs as irregular grains up to 0.2 mm. in diameter which join in the saccharoidal texture of the rock.

Apatite and fluorite are both automorphic. The former is in prisms up to 0.1 mm. long with rounded edges, while the latter is in minute fragmental grains. The yellow sulfide is almost absent from the section. Minute quadratic prisms with very high refractive indices and birefringence, and parallel extinction, that are believed to be zircon or rutile occur very rarely.

Alteration is very slight, though there is a little clouding in the section, especially in the amazonite. It consists of a few small nests of a pale green flaky mineral with moderate refractive indices and birefringence. These occur in the feldspars.

With the exception of the amazonite phenocrysts and the tendency towards automorphism in quartz and albite the texture of the rock is, on the whole, saccharoidal. The phenocrysts are by no means well formed, their margins being intergrown with quartz and albite grains, and included grains of these minerals are not uncommon far from their margins. Thus, their growth was certainly not completed, and probably not even started much before that of the other constituents. Furthermore, the automorphism of quartz and albite is not at all pronounced and it seems probable that only a small proportion of these minerals completed their growth before the other minerals of the groundmass, the period of crystallization of the quartz ending slightly earlier than that of the albite.

Strain shadows and anomalous biaxial character in quartz, and polysomatic texture in amazonite point towards differential movement within the dike, as does also the foliated structure of the rock. The movement must have occurred during the period of crystallization since there is no evidence of shearing. Whether it resulted from magmatic flow, or from movement of the walls of the fault in which the dike was intruded, could not be determined.

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[2] Rosenbusch's *Mikroskopische Physiographie*, vol. **1**, part 2, p. 584, No. 7, 1927.

Mineralogical Classification

On the basis of mineral composition the rock might be classed as either pegmatite or aplite. The fine grain and prevalence of allotriomorphic texture are characteristic of aplite. Though granophyric texture is absent, volatile constituents were present in greater amounts than in typical aplites, as shown by the alteration of the mafic constituents of the syenite, adjacent to the dike, to brown mica. The resulting fluidity of the magma probably accounts for the porphyritic development and slight automorphism. On the whole it seems best to consider the rock intermediate between aplite and pegmatite, and more nearly approaching the former in character.

Chemical Character

The chemical analysis of the rock is given in Table I. It is remarkable for the high soda-potash ratio and the extremely low content of calcium, magnesium, and iron.

Table I

Composition of Amazonite Aplite, Specimen 2–225

(Analyzed by Mary G. Keyes)

Chemical Analysis		Norm		Mode	
SiO_2	73.25	Or	23.35	Amazonite	48.0
Al_2O_3	15.23	Ab	53.97	Albite	28.5
Fe_2O_3	0.06	An	0.28	Quartz	19.0
FeO	0.52	Q	20.46	Zinnwaldite	3.0
MgO	0.06	C	0.41	Topaz	1.0
				Pyrrhotite?	0.1
CaO	0.03	Total	98.47	Fluorite	0.4
Na_2O	6.35			Apatite	
K_2O	3.95	Hy	1.02	Zircon?	
H_2O+	0.16	Total	99.49		
H_2O-	0.12			Total	100.00
TiO_2	none				
P_2O_5	0.03				
MnO	0.02				
Li_2O	p.n.d.				
Total	99.78				
Sp. G.	2.642 ± .002				

C.I.P.W. Classification: 1.4.1.4.

Spectrographic examination shows an appreciable amount of lithium, which is concentrated in the mica. Also this mineral appears to contain more iron than magnesium, and shows traces of rubidium.[3] These chemical characteristics of the mica are in agreement with the optical properties.

A comparison of the norm and mode of the rock, given in Table I shows a marked discrepancy between the amount of modal amazonite and Or. This is corrected if the excess of Ab over modal albite is added to the Or to make up the modal amazonite, indicating that the amazonite contains 54% of albite molecules.This suggests that the positive optical character of the mineral may be connected with a high content of albite molecules.

The very low An of the mode corresponds with the low indices of refraction of the albite in the thin section.

Though the alkali content of the rock, especially the soda, is unusually high, it can not be classed as a typically alkaline rock, since none of the accessory minerals characteristic of that series occur in it. Also the excess of soda is accompanied by an excess of silica, rather than a deficiency.

The chemical character of the rock is so unusual that none of the analyses given by Washington[4] agree closely with it. This is probably the result of a high degree of differentiation from the parent magma. The rocks which resemble it most closely in chemical composition are all extrusive or hypabyssal. Those for which the modes were examined generally showed minerals typical of the alkaline series, the closest being a commendite.[5]

Relation to Other Rocks on the Coast

The syenite in which the amazonite aplite occurs is cut by numerous small dikes which resemble the wall rock more or less closely in mineral composition. They are finer grained, and generally contain quartz in addition to the minerals shown by the syenite. They probably represent later differentiates of the magma from which the syenite crystallized, and the amazonite aplite may well be an extreme member of this series.

The syenite shows affinities with the alkaline series. It contains roughly 35% of albite. The mafic minerals consist of a little biotite and hornblende, but the latter has a negative optic axial angle of about 35°. Thus it may contain a high percentage of riebeckite molecules.[6] The low index feldspar has the optical properties of isorthoclase, which may indicate, by analogy with the suggestion for isomicrocline, that it also has a high soda content.

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[3] Personal communication from Prof. J. Papish, Cornell University.

[4] Washington, H. S. Chemical Analysis of Igneous Rocks: *U.S. Geol. Survey, Professional Paper*, No. 99, 1917.

[5] *Op. Cit.*, p. 160, No. 75.

The dike from which the specimen here described was taken was the only one of the kind encountered by the writer in his cursory examination of the island. However, Daly mentions a dike which appears to be somewhat similar, cutting granitite some 25 miles E. by S. of this locality on the mainland opposite Jigger Island.[7] This suggests that the series of which the aplite is a member may be fairly extensive.

[6] Winchell, A. N. Further Studies in the Amphibole Group: *Amer. Mineral.*, vol. **XVI,** p. 262, 1931.

[7] Daly, R. A. The Geology of the Northeast Coast of Labrador: *Bulletin of the Harvard Museum of Comparative Zoology*, vol. **XXXVIII,** pp. 213–214, 1902.

BURKEITE, A NEW MINERAL SPECIES FROM SEARLES LAKE, CALIFORNIA

WILLIAM F. FOSHAG,[1] *U. S. National Museum.*

INTRODUCTION

Among the new compounds found in the laboratories of the American Potash and Chemical Corporation, in a study of the equilibria relationships of the salts of the Searles Lake brines, was one first prepared by Mr. W. E. Burke[2] in 1919. This new compound is a double sulfate and carbonate of sodium, $2Na_2SO_4 \cdot Na_2CO_3$ and the name burkeite has been given to it. "Although its native occurrence has not hitherto been reported, and although it does not seem to be a constituent of the Searles Lake salt body, we fully expect to hear of it from Owens Lake, or some of the other alkaline lakes, now that attention has been called to its existence. For this reason, and also as a matter of convenience in referring to a material formed in the plant at the rate of some thousands of tons a week, we have given it a name, burkeite."[3]

In studying the samples of the well G-75 drilled by the U. S. Geological Survey during its search for potash, attention was attracted to small *x*-shaped crystals sparingly present in the sample from the lower portions of the salt crust. These same samples yielded the new mineral schairerite.[4] The new mineral seems to be confined to samples from a depth of 115–130 feet, the lowest sample taken. These *x*-shaped crystals and others, together with some masses of solid salt prove to have the chemical composition and optical properties of burkeite as produced artificially at Searles Lake.

Because of the recommendation of John E. Teeple cited above and particularly in view of W. E. Burke's valuable and difficult researches on equilibria in Searles Lake minerals, I think it is desirable to retain the name *burkeite* for this new mineral species. I am indebted to Mr. W. A. Gale, Director of Research, American Potash and Chemical Corporation, for samples of artificial burkeite made in their laboratories and for interesting and valuable information on the equilibria relationships of burkeite and its possible occurrence in the salt crust of Searles Lake.

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[1] Published by permission of the Secretary of the Smithsonian Institution.

[2] *Jour. Ind. Eng. Chem.*, vol. **13**, p. 249, 1921.

[3] Teeple, John E., Industrial Development of Searles Lake Brines, p. 32, 1929.

[4] *Am. Mineral.*, vol. **16**, pp. 133–139, 1931.

OCCURRENCE

Burkeite occurs sparingly in the samples from a depth of 115–130 feet in well G-75. Undoubtedly more is present in these samples than an examination would indicate for only those grains or crystals showing certain peculiar markings can be readily distinguished from many of the accompanying salt grains. Crystals and groups of crystals seldom exceed 4 millimeters in maximum dimension, but some of the broken fragments of the massive mineral are much larger. In the sample from a depth of 115–125 feet the burkeite occurs in flat, cushion-shaped crystals, groups of small irregular crystals and fragments of massive mineral. This latter form presumably represents thin beds or massive lumps broken in the course of drilling. The salts of this sample are clean and contain trona, in clear laths; halite in cleavages and fragments; pirssonite in flat diamond-shaped crystals, also hemimorphic crystals; borax in lumps; northupite in small rough octahedrons; clear, sharp gay-lussite crystals; sulfohalite in clear cubo-octahedrons; and rarely small hanksite crystals. The burkeite is rather intimately associated with the trona or has been embedded in a very fine grained gay-lussite sand.

The lowest portion of the well, from 125–130 feet, would be classed as a more "clayey" sample but the clay is, for the most part, very finely crystalline gay-lussite. This formed the matrix for many of the other minerals, including the burkeite. The burkeite is more abundant in this sample than in the first and occurs as thin, cushion-shaped crystals, *x*-shaped twins, and round masses with a mulberry-like surface. All these forms were apparently scattered singly through the gay-lussite "clay." Associated minerals are clear, sharp gay-lussite crystals; pirssonite in relatively large crystals; northupite in pale yellow to gray rounded octahedrons; thenardite in rough blades without distinct crystal form; tychite in minute sharp, clear octahedrons; schairerite in sharp, steep rhombohedrons; minute ivory colored crystals of calcite, and very rarely small crystals of hanksite.

CHEMICAL COMPOSITION

It was very difficult to obtain a reasonably pure quantity of crystals for analytical investigation, so the massive lumps were used for analysis. Fortunately these lumps were satisfactorily pure, better, in fact than could have been obtained by attempting to select crystals. The mineral is easily soluble in water and standard analytical procedures were used. The results of the analysis is given in the table below:

Analysis of Burkeite

	Searles Lake	Theoretical Composition
Insoluble	0.04	
Na_2O	47.89	47.69
K_2O	None	
SO_3	39.96	41.02
CO_2	11.72	11.29
Cl	0.09	
H_2O	0.04	
	99.74	

The analysis gives satisfactorily the formula, $2Na_2SO_4 \cdot Na_2CO_3$.

Burkeite is easily and completely soluble in water, the solution giving the usual reactions for sulfates and carbonates. Before the blow-pipe it fuses easily and quietly to a clear bead, when hot; white and crystalline when cold; and colors the flame an intense yellow. The mineral is alkaline to tumeric paper.

Crystallographical Properties

Crystals of burkeite are common in the material available but are not suitable for crystallographic measurements. A narrow face, considered here the side pinacoid, is usually present on the crystals and is sometimes sufficiently smooth to give fair reflections. The

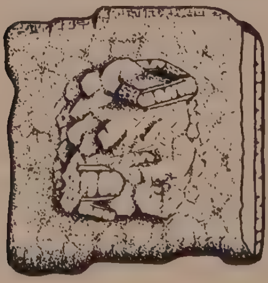

Fig. 1

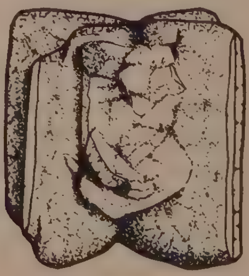

Fig. 2

Fig. 1. Simple crystal of natural burkeite, showing broad front pinacoid, prism and side pinacoid.

Fig. 2. X-shaped twin crystal of natural burkeite.

front pinacoid is broad and rough with a shagreened surface and yields no reflections. Between the two pinacoids is often a narrow prism, distinct, but mat. The third pinacoidal position is occupied by numerous minute terminations, apparently in parallel position but giving this part of the crystal a rough appearance. Figure 1 is a drawing of one of these simple crystals.

The twin crystals are made up of individuals of the same habit as the simple crystals intergrown to form an *x*-shaped twin. Their appearance varies somewhat, depending on the relative thickness of the individual crystals. Where these crystals are thin the twin is decidedly *x*-shaped; where the crystals are thick the twin may resemble hexagonal prisms with two pairs of plane faces (the side pinacoids), each pair separated by a rough median line; and two rough re-entrant faces. Complex aggregates suggest that there is also a transverse twinning but this could not be definitely established on the material available. The re-entrant angles of the twins are partially filled with rough crystals in apparently random position (Figure 2). The only angular measurements obtainable were those between the side pinacoid faces of the twinned crystals. These measurements, while not good, were fairly satisfactory and average 59°42′ and 120°12′. If we assume that the twinning plane is *m*(110), the prismatic angle 59°42′ would yield an axial ratio of: $a:b=0.574:1$. Certain prismatic markings in some grains observed under the microscope gave a measured angle of 56° when rolled to as near a normal position to the axis as possible. Unfortunately no direct measurements could be made on the prism itself.

Often a large number of crystals are intergrown to form reticulating aggregates of plates. Another form commonly met with is small pea-shaped nodules, their surface being composed of relatively bright faces of the side pinacoid, giving some suggestion of a facetted grain. There are also irregular warty masses resembling mulberries.

OPTICAL AND PHYSICAL PROPERTIES

The color of burkeite is white to pale buff or slightly grayish. The luster is cryolitic, but usually glassy on the side pinacoid.

Under the microscope the mineral is strongly birefracting with low indices of refraction. The mineral is biaxial, negative, with medium small axial angle. $2V=34°$. Dispersion distinct, $r>v$. The indices of refraction, by the oil immersion method, were determined to be as follows:

	α	β	γ	Determined by
Natural mineral	1.448	1.489	1.493	W. F. Foshag
Natural mineral	1.449	1.488	1.491	Jewell Glass
Artificial salt	1.450	1.490	1.492	W. F. Foshag

The plane of the optic axes is parallel to the front pinacoid. The orientation is: $X = c$; $Y = a$; $Z = b$. Figure 3 is a camera lucida sketch of a thin cross section of a twinned crystal showing the optical orientation as well as the twinning habit.

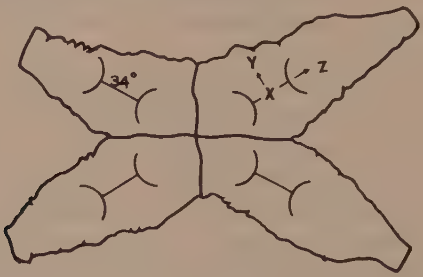

Fig. 3. Camera lucida sketch of thin cross section of natural burkeite crystal showing twinning and optical orientation.

The specific gravity, measured by floating in a heavy solution, was found to be 2.57. The actual density is probably slightly higher, since grains free from minute inclusions were unobtainable. Burkeite readily scratches calcite but does not scratch fluorite. Its hardness is, therefore, 3½. It is very brittle, breaking with a rough conchoidal fracture and shows no evidence of cleavage.

Relation to Other Salt Minerals

The equilibrium relationship of burkeite to the other saline minerals of Searles Lake has been worked out by W. E. Burke and his co-workers and the equilibrium diagrams have been published in John E. Teeple's "The Industrial development of Searles Lake Brines." A study of the system, sodium chloride- potassium chloride- sodium sulfate- potassium sulfate- sodium carbonate-potassium carbonate-water, suggests that simple evaporation of normal Searles Lake brine will not yield burkeite in stable equilibrium with the other salts. On this point W. A. Gale[5] has the following to say:

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[5] Personal communication.

In the case of Searles Lake, the brine from the lower portions of the main salt body is a considerable distance from the end point of crystallization of the preceding eight component systems (K-Na-H-SO_4-CO_3-Cl-B_2O_4-PO_4-H_2O). The relative proportions of the sulfate, carbonate and potassium ions indicate that the point representing this brine falls on the boundary between the hanksite and glaserite fields of the phase rule diagram. It is also saturated with halite, borax and trona, thus being trivariant. Thenardite and burkeite are not stable phases in contact with this lower brine at lake temperatures (about 22.5°C.), although only a slight change in liquid phase composition is necessary in order to reach the divariant point in metastable equilibrium with thenardite, burkeite, glaserite, halite, borax and trona. A considerable change is necessary, however, before burkeite could be a stable solid phase.

On the other hand the marginal and surface brines vary greatly in composition, and we have found considerable thenardite in marginal portions of the deposit near the surface. Therefore, there seems no reason why burkeite should not also occur in certain parts of the deposit in equilibrium with local brines.

We have obtained artificial crystals of hanksite in the laboratory, but they are very slow in growing. Starting at the above mentioned metastable point, months, or even years, may be required to reach equilibrium even after hanksite seeds appear or are intentionally added. Therefore, in the original deposition of the salt strata of the lake, we think it possible that burkeite was first precipitated along with thenardite, glaserite, etc., and that eventually hanksite appeared and crystallized slowly at the expense of these other sulfate phases. Large quantities of glaserite remain, but burkeite and thenardite are now absent from this portion of the deposit except possibly as inclusions within other crystals or within dense aggregates of other salts.

The mineral assemblage found in the samples—thenardite, burkeite, trona and halite—and the absence of glaserite and the very rare occurrence of hanksite suggests that the brines from which these salts crystallized were simpler in composition than the normal Searles Lake brines, being deficient in potash salts, corresponding more nearly to the system: $NaHCO_3$-Na_2CO_3-Na_2SO_4-$NaCl$-H_2O.[6] This variation from the normal brine may be due to the vagaries of underground drainage, or, as already suggested by W. A. Gale, may represent an ancient stage in the evaporation of these brines. Gale states:

> We note that the association of natural burkeite from well G-75, includes borax, trona, halite, thenardite and some hanksite, but an absence of glaserite. The original mother liquor in contact with these solid phases would, therefore, correspond to the liquid phase represented by point 288, Diagram 17, shown on page 103 of Teeple's book, except for the addition of borax, trona and the less soluble minerals. These latter, however, would not be expected to greatly affect the solubility relations of the other salts at ordinary temperatures. In other words, the solution from which

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[6] System XXIV, Diagram 50, *Industrial Development of Searles Lake Brines.*

the natural burkeite crystallized must have been at the opposite side of the hanksite field from that of normal Searles Lake brine as found in the main salt body today.

In this connection it is interesting to note that the relative proportions of the principal salts in Owens Lake brine prior to the start of crystallization in 1921 were such as to place the brine within the stable portion of the burkeite field, about midway between points 288 and 4 (Teeple's Diagram 17), upon reaching saturation with a sulfate phase.

Since the Searles Lake salt deposit resulted from the evaporation of saline waters which had originally overflowed from Owens Lake, it is quite conceivable that some of the early stages of crystallization should take place from brines having compositions falling along the boundary between the burkeite and thenardite fields and approaching saturation with hanksite at point 288 as the concentration of potassium increased.

In a crystallographical and optical study of an artificial salt submitted to him as $2Na_2SO_4 \cdot Na_2CO_3$, Austin F. Rogers[7] obtained the following optical properties:

$$\alpha = 1.463, \qquad \beta = 1.469, \qquad \gamma = 1.480.$$

These values are those of an optically positive mineral with small axial angles and do not correspond to the values obtained on either the natural mineral or the artificial burkeite as produced at Searles Lake. The crystallography of Rogers' salt suggests that it may be, in part, thenardite as both the crystal habit and the angular measurements suggest that mineral.

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[7] *Am. Jour. Sci.*, vol. **11**, pp. 473–476, 1926.

NOTES AND NEWS

SODA-ALUNITE FROM MOLOKAI, HAWAIIAN ISLANDS

J. D. Laudermilk, *Pomona College, Claremont, California.*

A white, chalky mineral from the desert strip of Molokai was collected by Mr. Ray Fosberg of the University of Hawaii. When first collected, the mineral was tentatively identified as a clay mineral. Samples of the material were sent to Pomona College for study and qualitative tests established its identity as alunite.

Wentworth[1] makes no mention of alunite as occurring in the desert strip. The fact that he did not observe the presence of the mineral is not very remarkable. Unless especially looked for the material, like the samples submitted, might easily be identified as a compact, chalky limestone. Wentworth states that calcium carbonate occurs abundantly as joint fillings and nodular masses in basalt and also as casts of decayed roots and shrubs.

As to the occurrence of our sample, Mr. Fosberg[2] says:

> . . . The material was found near the middle of the desert strip, about three miles from the coast. A very small outcrop was found and pieces were scattered here and there over a considerable area. It did not seem that they could have all come from this one small deposit. . . .

A microscopic study of the mineral made by A. O. Woodford of Pomona College, shows the soft, white, chalky masses to be made up of minute equidimensional crystals, 1.5 to 4.0 microns in diameter. The crystals are probably rhombohedrons, perhaps chiefly $(60\bar{6}5)$, as the face angles are commonly about 82 and 98 degrees, and the long diagonal is Z'. A few rectangular grains are probably unit rhombohedrons. Alpha $= 1.570 \pm .005$; $\gamma - \alpha = .020$ or greater, as indicated by addition and subtraction effects with the gypsum plate.

A preliminary spectrographic analysis of the sample taken for the quantitative determinations was made by T. G. Kennard of the Claremont Colleges and showed the following elements in the proportions estimated:

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[1] Wentworth, Chester K., The Desert Strip of West Molokai: *University of Iowa Studies, New Series* No. 89, vol. **XI,** No. 4, pp. 41–56, 1925.

[2] Mr. Ray Fosberg, University of Hawaii. Personal communication.

Element	*Amounts*
Al	large
K	small
Fe	“
Na	“
Cu	very small
Si	“ “
Ca	trace
Sr	“
Ba	“
Mg	“
Ti	“
V	“
B	“
Li	extremely minute trace
Mn	“ “ “
Pb	“ “ “
Rb	“ “ “
Cs	“ “ “

A chemical analysis of the material made by the writer, showed it to have a composition which is in agreement with that of an alunite from Kanowna, West Australia, as given by Doelter.[3] The two analyses follow below:

Alunite from Molokai			Alunite from Kanowna	
	per cent	molecular ratios, atomic wts. 1934		per cent
Na_2O	4.62	.0745	Na_2O	4.07
K_2O	6.08	.0646	K_2O	5.42
MgO	trace		MgO	—
CaO	0.28	.0050	CaO	—
Al_2O_3	34.64	.3398	Al_2O_3	36.46
Fe_2O_3	2.16	.0135	Fe_2O_3	0.24
SO_3	37.02	.4624	SO_3	37.64
P_2O_5	—		P_2O_5	—
SiO_2	0.04		SiO_2	0.95
H_2O (total)	15.38	.8537	H_2O (above 110°)	15.45
TiO_2	0.60	.0075	H_2O (below 110°)	0.06
	100.82			100.29

A spectrographic analysis of the insoluble fraction given as TiO_2 in our summation showed it to contain also Mg, Si, Fe, etc., but in quantities too small to justify separation.

The high percentage of soda (54 molecular per cent Na-alunite) justifies the classification of the mineral as soda-alunite in the broad sense.

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[3] Doelter, C., *Handbuch der Mineralchemie*, vol. IV, Pt. 2, p. 496, No. 6, 1929.

STIBNITE IN QUARTZ

Noel H. Stearn, *St. Louis, Missouri.*

At least two known localities in the United States have yielded what may be considered to be a rare mineral association—stibnite inclusions in quartz crystals.

In August, 1932, Dr. Paul F. Kerr, Professor of Mineralogy at Columbia University, New York, discovered at the Golden Spike mine, Imlay Canyon, Pershing County, Nevada, a number of quartz crystals containing slender, acicular inclusions of stibnite. They were associated with a gold-bearing quartz vein in a small prospect tunnel on the west side of Humboldt Range. One crystal furnished for this study (see Figure 1-A) is about 4 centimeters long, terminated by broken and irregular ends as if it had grown directly across a cavity and anchored at both extremities. The 6 irregular crystal faces of a unit prism, all showing distinct horizontal striations, have not been symmetrically developed.

Within the crystal, and never quite reaching its surface at any place, are numerous thread-like inclusions recognized by their crystal habit, lead gray color, and metallic luster to be stibnite. These have a maximum length of about 3 centimeters. All are oriented at angles to the principal axis of the crystal so that the inclusions form a criss-cross net work of slender stibnite rods which are fairly evenly distributed throughout the middle portion of the crystal. For the most part the stibnite rods are straight and oriented in such a way as to simulate parallelism with one or another of the rhombohedral, pyramidal, or trapezohedral faces which would be expected to terminate the prism if the quartz crystal were complete, although this parallelism may be suggestive rather than actual. A similar orientation of slender rutile threads may be observed in a quartz crystal in the collection of Prof. W. O. Shipton at Washington University, St. Louis, Mo.

In May, 1932, numerous smaller quartz crystals containing stibnite inclusions were found at the Parnell Hill and Gap Ridge Mines of the Southwestern Quicksilver Company in the recently discovered cinnabar district of Pike County, Arkansas. In this locality they occur associated with cinnabar and dickite in fractures in a massive quartzite formation. Rarely the quartz crystals are to be found completely embedded in dickite so that they show terminations at both ends. An example of such crystals is shown at B in Fig. 1. The ends are terminated by the rhombohedrons $r(10\bar{1}1)$

and $z(01\bar{1}1)$ which are not quite equally developed, but their departure from symmetry is not marked. No other modifying faces appear. Within this singularly clear and glassy crystal the stibnite inclusions occur as very fine, cobwebby, lead gray threads with a gunmetal luster. None of the stibnite threads is straight, and the longest of them barely exceeds 1 centimeter in length, few being over ½ centimeter long. They are very irregularly distributed through the crystal, occurring as twisted, tangled nests with a cord of stibnite threads connecting them. It is as if a rope of stibnite included near the junction of two prism faces of the crystal had been frayed at each end, giving off a tangled jumble of broken threads. Under high magnification it can be seen that the threads themselves are still further frayed and split into smaller threads.

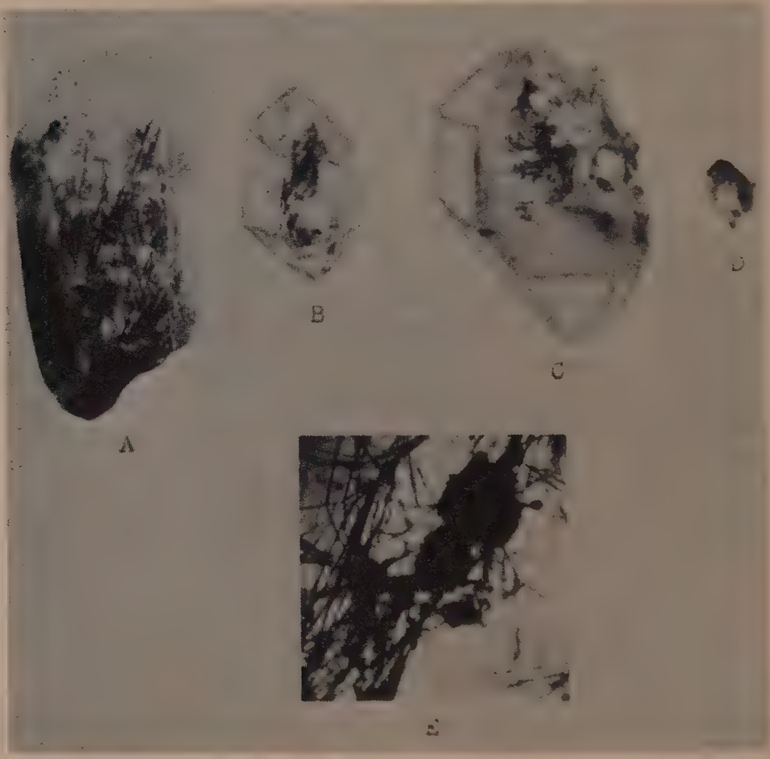

Fig. 1

(Photographs by H. L. Koch, Washington Univ., St. Louis, Mo.)

Associated with the stibnite inclusions are about one dozen small scarlet inclusions, the largest being about half the size of a pinhead. These are too irregular in shape to be called globules and too rounded to be called crystals. They resemble former crystals which have had all corners fused or dissolved into gently rounded shapes. In some cases they hang to the stibnite threads like minute red berries with stibnite stems. In other cases they are found intimately associated with a rope of stibnite threads and are penetrated by them. In one case the scarlet inclusion shows a fuzzy halo of stibnite threads. From their color, the vague remnant of their crystal form, and their general association the inference is drawn that they are composed of cinnabar.

Figure 1-E shows a photograph of the inclusions in Figure 1-B magnified 7 times. The frayed threads of stibnite are immediately recognizable. The irregular, opaque masses in the middle of the photograph are cinnabar.

High magnification shows rare colorless inclusions of shapes and sizes similar to the cinnabar inclusions, suggesting that they are casts of cinnabar inclusions from which the cinnabar has disappeared. There also appear slender, colorless inclusions resembling casts of stibnite from which that mineral has been removed.

The order of crystallization as shown by the association in this crystal seems to have been: first, stibnite; second, cinnabar; and third, quartz.

In the same locality numerous other quartz crystals have been found containing cinnabar and stibnite inclusions. The habit of the stibnite inclusions differs in different crystals. Stibnite sometimes occurs as tiny flakes, sometimes as minute ribbons with the flat faces showing silvery gray luster, sometimes as masses shaped like small burrs, and sometimes with no observable regularity of habit or distribution. In Figure 1-C a combination of a threadlike and a flaky habit is illustrated.

In the same place where these crystals were found, drusy masses of smoky quartz crystals intimately intergrown with cinnabar crystals have been frequently noted. The association suggests that the discoloration of the smoky quartz is due to stibnite. Figure 1-D shows one crystal from such a drusy quartz mass in which the stibnite inclusions can be definitely recognized. The terminated end is clear quartz. The inclusions begin about where the rhombohedral faces join the prism faces, and grade rapidly into a dense, black mass. The evidence from this crystal suggests that the smoky quartz in this locality is colored by stibnite.

Some parts of the faces of the quartz crystal shown in Figure 1-C are etched and pitted with finely granular pyrite which has been partly oxidized. This is significant in indicating that the quartz crystals came from the sulphide bearing hot water solutions associated with the deposition of the cinnabar and stibnite, rather than from later meteoric waters depositing silica in previously mineralized fractures. The sequence of crystallization as observed from all specimens is: first, stibnite; second, cinnabar; third, quartz; fourth, pyrite; and fifth, dickite.

SCHROECKINGERITE FROM BEDFORD, NEW YORK

E. J. Armstrong, *Bryn Mawr College*.

On a recent visit to Kinkel's quarry, just outside of Bedford, N. Y., pegmatite specimens were collected that exhibited a few small fragments of a greenish yellow mineral, thought at the time to be autunite. On further examination, however, it was found that its optical constants, especially its indices of refraction, were not in agreement with those of autunite.

The mineral was finally determined to be schroeckingerite, a hydrous uranium carbonate, named after Baron Schroeckinger in 1873 by A. Schrauf.[1] It is stated by Winchell[2] to be an alteration product of uranium minerals. Schrauf's material came from Joachimstal in northwestern Czechoslovakia,[3] as did that later described by E. S. Larsen.[4] The mineral has not, to the writer's knowledge, been described from any other locality.

The mineral is apparently monoclinic and has perfect $\{010\}$ and distinct $\{100\}$ cleavages, giving a large number of laths exhibiting inclined extinction and the acute bisectrix, with a smaller number exhibiting parallel extinction and a flash interference figure. All the laths are extremely small, the larger fragments of the material being made up of clusters of small laths.

The optical characteristics were determined to be as follows: Extinction $30° \pm$; $r > v$ strong. Very strong crossed dispersion giving abnormal interference colors in reddish brown and blue. (−)2V = 40°−45°±. Indices of refraction: $\alpha = 1.658$, $\beta = 1.682$, $\gamma = 1.685$. (Larsen and Berman[5] record: $\alpha = 1.658$, $\beta = 1.690$, $\gamma = 1.685$. The limit of experimental error of the writer's determinations is probably about 0.003.) Pleochrosim: X = colorless, Y = very pale greenish yellow, Z = pale greenish yellow.

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[1] *Tscherm. Min. Mitt.*, **1873,** p. 137.

[2] Winchell, A. N., *Elements of Optical Mineralogy*, 3rd edit., 1933, Part **II,** p. 86.

[3] Hintze, *Handbuch der Mineralogie*, Bd. **1,** Abt. 3, Hälfte 1, 1930.

[4] Larsen, E. S., *The Microscopic Determination of the Nonopaque Minerals, U.S.G.S., Bull.* **679,** 1921.

It is hoped that with further study of the schroeckingerite and of the other uranium minerals whose manner of occurrence is similar, especially in the Kinkel's quarry pegmatite and other southern New England pegmatites, something may be learned concerning the nature of their interrelations.

The writer is indebted to Dr. Edward H. Watson and Dr. Dorothy Wyckoff of Bryn Mawr College for their assistance in checking the above results and to Miss S. Grace Hower of Bedford, N. Y., for collecting additional material.

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[5] Larsen, E. S., and Berman, H., *The Microscopic Determination of the Nonopaque Minerals*, 2nd edit., *U.S.G.S. Bull.* **848.** 1934.

BOOK REVIEW

DER LÖSS UND SEINE GEOTECHNISCHEN EIGENSCHAFTEN, Scheidig, Alfred. 233 p. with 132 text figs. and 6 tables. *Dresden* and *Leipzig*, Th. Steinkopf, **1934.** (Bound, RM 20.)

It is gratifying to see that someone has undertaken the arduous but useful task of summarizing most of the available information on the much debated loess problem. The magnitude of the task can be inferred from the author's bibliography which contains no less than 580 references.

It is true that this summary was primarily made as a background for the main topic which treats of loess from the standpoint of the civil engineer, as stated in the subtitle. Nevertheless, fully one-half of the text, comprising two of the three main chapters is sufficiently general in nature to interest the geomorphologist, sedimentary geologist, pedologist and geographer.

The first part (pp. 3–72), under the general title of "geological and geographical principles," discusses the characteristics of "true" loess, the distribution of loess deposits on the earth's surface, morphology of loess-landscapes, genesis, classification and economic importance of loess. Numerous sketch-maps and diagrams illustrate the description of occurrences in the various countries and many half-tones accompany the discussion of typical loess-landscapes. [Nothing is definitely known concerning the origin of the name "loess" beyond the fact that it was in use early in the 19th century, as a folk-term for particular kinds of soils along the Middle Rhine. Its relation to the German words for loose (=lose) and loosening (=lösen) is merely suggested. Neither can a strict definition of loess be given, as yet; there are no less than 20 hypotheses which have been proposed for its mode of origin. The author considers it one of the most important tasks of loess research in the near future to formulate a definition that will satisfy all parties concerned!]

The second part (pp. 73–124) entitled "physical properties of loess" treats of such divers topics as mineralogical, chemical and granular (mechanical) composition; structure, porosity, plasticity, permeability, and behavior toward water, varying loads, frost, etc. The mineralogical composition is accorded only five pages, a reflection of the lack of information available. Quartz is always predominant and averages 60%–80% of the total mineral matter. This accounts for the fact that loess never weathers into fat clays, but always remains lean sandy loams with little clay (8%–15% on the average). Next in importance are feldspars and lime carbonates which may form the well-known lime concretions, although lime free loess is also found. No less than 54 different minerals have been reported from a Chinese loess, but the great need for a systematic comparative petrographical study of the world's loess deposits is emphasized. From the mechanical analyses it is clear that loess and its congeners are all characterized by the preponderance of the fraction 0.05–0.01 mm. and the absence of the colloidal fraction, less than approximately 0.001 mm. in diameter.

The third part (pp. 125–204) under the title "loess and geotechnics" is devoted to the engineering applications of the foregoing discussions—a subject which seems to have been largely overlooked by engineers. It treats, in turn, of the problems encountered in using loess for structural foundations, for hydraulic purposes, for water supplies and for technological purposes. A topical and a geographic index, besides the lengthy bibliography, referred to above, conclude this monograph, of which the publication was eminently justified.

M. W. Senstius

PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

Anniversary Meeting, November 1st, 1934

The following were elected officers and members of the Council:—

President, Sir Thomas H. Holland; *Vice-Presidents*, Mr. Arthur Russell, Sir William H. Bragg; *Treasurer*, Mr. F. N. Ashcroft, *General Secretary*, Mr. W. Campbell Smith; *Foreign Secretary*, Prof. A. Hutchinson; *Editor of the Journal*, Dr. L. J. Spencer; *Ordinary Members of Council*, Prof. P. G. H. Boswell, Prof. H. L. Bowman, Dr. L. Hawkes, Mr. J. B. Scrivenor, Mr. T. Crook, Dr. W. F. P. McLintock, Mr. L. R. Wager, Dr. A. K. Wells, Prof. A. Brammall, Mr. C. W. Mathews, Dr. P. T. Phemister, and Dr. H. H. Thomas.

Dr. L. J. Spencer: *Murnpeowie (South Australia), a granular type of meteoric iron.* A mass found in 1909 weighing 2520 lb. is preserved in the School of Mines, Adelaide. Study of an etched slice shows remnants of an original lamellar octahedral structure from which granular kamacite has been developed by heat treatment of the mass. The grains of kamacite are irregular in outline and orientation and show well marked Neumann lines. A narrow, finely granular zone on the outside of the mass shows the effect of another and later heat treatment during the flight of the meteorite through the earth's atmosphere.

Mr. J. Adam Watson: *Colour reactions in the micro-chemical determination of minerals.* Most of the elements occurring in minerals can be determined qualitatively by highly sensitive colour reactions carried out in solutions prepared from minute quantities of the minerals. Solution is effected either with HCl or by fusing in a bead of sodium carbonate in a loop of platinum wire. The basis of the work is mainly Dr. F. Feigl's "Qualitative Analyse mit Hilfe der Tüpfelreactionen," published in 1931.

Mr. A. R. Alderman: *Almandine from Botallack, Cornwall.* Well crystallised icositetrahedral garnets from Botallack, Cornwall, give the following analysis; SiO_2 35.58, TiO_2 trace, Al_2O_3 21.94, Fe_2O_3 none, FeO 38.54, MnO 0.70, MgO 0.68, CaO 1.68, H_2O- 0.12, =99.24. The garnet is thus very rich in the almandine molecule. This and many other analyses of almandine-rich garnets, show aluminium in excess of that required by the accepted garnet formula.

Mr. B. Lightfoot, Mr. A. M. MacGregor and Mr. E. Golding: *The meteoric stone seen to fall in the Mangwendi native reserve on March 7, 1934.* This is the first meteorite to be recorded from Rhodesia. It fell at 12:45 p.m. about 40 miles east of Salisbury and was broken in its fall amongst granite boulders. The pieces recovered weighed 52¼ lb., but the whole must have been about 60 lb. The main mass, weighing 48 lb. 11 oz. (22 kg.) has been presented to the British Museum by the Government of Southern Rhodesia. It is a grey chondritic stone of the Soko-Banja type, consisting of olivine, enstatite, and feldspar with metallic nickel-iron (3.17%) and troilite (4.98%).

Mr. F. A. Bannister: *The crystal-structure of the bismuth oxyhalides.* Minute single crystals of the BiOCl, BiOBr and BiOI have been prepared by a diffusion method. They yield perfect Laue, rotation and oscillation photographs which show that all three salts are tetragonal and have a similar crystal structure to that of matlockite (PbFCl). The bismuth and oxygen atoms of these compounds are more closely packed together than the corresponding lead and fluorine atoms of matlockite. Powder photographs show that Daubreeite (1876) is identical with artificial BiOCl.

MINERALOGICAL SOCIETY OF AMERICA

—Progress Report of the Committee on Affiliation—

December 1934

In the early part of the year 1934 the Geological Society of America suggested informally that its affiliated societies might cooperate in surveying their fields of activity and publication with respect to the parent society. As a result, three Societies, the Seismological Society of America, the Paleontological Society and the Mineralogical Society of America, appointed committees on affiliation to confer with the Executive Committee of the Geological Society of America.

The affiliation committee appointed by the Council of the Mineralogical Society of America consisted of the Editor of the American Mineralogist, together with the Treasurer and Secretary of the Society. During the year this committee has cooperated in the survey and a considerable exchange of information has ensued which has been of mutual advantage.

It is too early to predict the ultimate outcome of this study, but steps have already been taken toward more clearly defining the boundary between the field of publication of the Geological Society and that of the Mineralogical Society. Furthermore, it is expected that machinery will soon be available for an exchange of papers which should improve the publication program of both organizations. The probable result will be, that papers on Mineralogy, Chemical Mineralogy, Crystallography and allied subjects including the less elaborate papers on Petrography will be published in the American Mineralogist. On the other hand, papers requiring unusual facilities for publication or papers of broad general interest will be published in the Bulletin of the Geological Society.

No restriction has been placed upon the Editor of either Society in the acceptance of papers, and the Society in which a paper originates is still the final judge concerning the disposition of the paper. However, a closer contact has been established between the editorial offices of the two societies whereby each office is to confer with the other concerning papers to be published in the field of Mineralogy, Petrography, Crystallography or related subjects and it is hoped the resultant screening and classification of papers may be of benefit to all concerned.

In view of the relationship outlined above and the supply of papers now in the Editor's hands, it has been appreciated that an increase in the size of the American Mineralogist will be necessary, if papers are to continue to be published promptly. In order to assist in caring for this increase in the size of the Journal the 1934 Council of the Geological Society has generously appropriated One Thousand Five Hundred Dollars ($1,500) from the Penrose Fund for the calendar year 1934. The 1934 Council of the Geological Society has also approved a similar item for the year 1935. The latter appropriation, however, is subject to the approval of the 1935 Council of the Geological Society.

The funds thus appropriated will be used to help defray the actual cost of publication of the American Mineralogist, in addition to the income from the Roebling Bequest and funds furnished by the Mineralogical Society. It is hoped that during the year 1935 the additional funds available will result in still further improvement in the publication program of the Society.

It is particularly fortunate that the survey of the publication situation and resulting support by the Geological Society has occurred at the present time. In recent years the Editor of the American Mineralogist has been forced at times either to refuse papers offered for publication, or to request financial assistance from the authors because the Society had reached the limit of the amount it could spend on publication. It is hoped that additional funds now available will materially raise the publication limit and relieve the pressure on the Editor's office during 1935.

The Committee is continuing its work through 1935. As progress reaches such a stage that it can be definitely outlined, reports will be made to the Society. It should be pointed out, however, that although the results of the Committee's work may be stated rather simply it has been necessary to attend to many time consuming technical details. It is to be hoped therefore, that the members of the Society will be patient in judging progress, and will realize that questions of policy affecting affiliated Societies require careful and extended study.

Your Committee wishes to take this occasion to express its appreciation of the cordial spirit of cooperation manifested by the Geological Society of America. The friendly attitude of both the Officers and the Council of the Geological Society has made the work of the Committee a pleasure.

Respectfully submitted,
WALTER F. HUNT
WALDEMAR T. SCHALLER
PAUL F. KERR, *Chairman*

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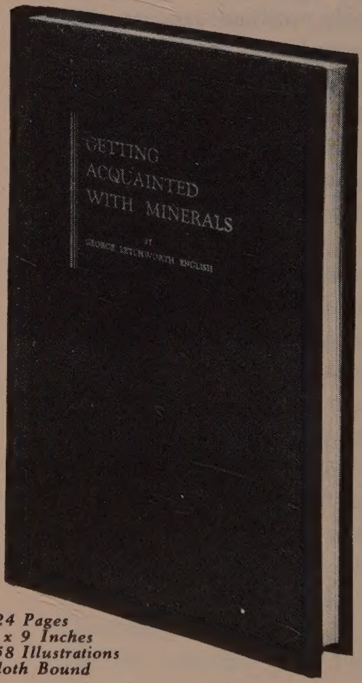

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